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ABSTRACT

Designed for student use in "Energy Conservation and Passive Design Concepts," one of 11 courses in a 2-year associate degree program in solar technology, this manual provides readings, bibliographies, and illustrations for seven course modules. The manual, which corresponds to an instructor guide for the same course, covers the following topics: (1) conservation as an energy source; (2) energy conservation and human effort; (3) types and efficiency of heating, ventilation, and air conditioning systems; (4) domestic water use and conservation, water heating, and solar water heating systems; (5) the energy required by lighting and particular appliances; (6) passive solar design considerations, such as building design, placement, interiors, window systems, and thermal storage; and (7) passive solar design approaches, e.g., direct gain, thermal storage wall, attached sunspace, thermal storage roof, and convective loop. (AYC)

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SOLAR ENERGY

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

Student Material

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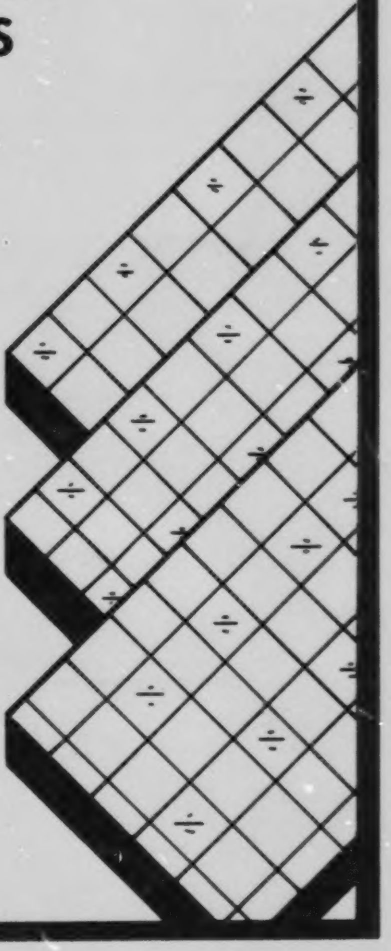

JC 830 239

NAVARRO COLLEGE
CORSICANA, TEXAS

Student Material

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

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1982

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4

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS
Student Material

CONTENTS

Preface v

Acknowledgments. vii

Use of the Student Material. ix

Conservation as an Energy Source VII-S-1

Energy Conservation and Human Comfort. VII-S-33

HVAC and Energy Conservation VII-S-155

Water Use and Energy Conservation. VII-S-241

Illumination, Appliances and Energy Conservation VII-S-295

Passive Solar Design Considerations. VII-S-341

Passive Solar Design Approaches. VII-S-401

PREFACE

The United States is facing one of its most challenging decades in recent history. Fuel supply and inflationary prices have forced us to consider alternate energy sources as a means of preserving our standard of living, industrial society, and economic stability. One such alternative is solar.

Presently, foreign crude oil provides the raw material for about one-half the liquid fuel production in the U.S. Political instability in foreign oil-producing countries underscores the need to decrease our ever-growing dependency on foreign energy sources and to lessen our vulnerability to such imports. Solar energy as an alternate can be used as a renewable domestic energy source and to supplement our increasing appetite for oil.

To help bring about the potential for solar energy, there must be a cadre of trained technicians to design, install, troubleshoot, and market solar energy so that the consumer can feel comfortable in the market's ability to service and react to his/her solar energy needs.

With the support of the National Science Foundation, Navarro College, in consortium with North Lake College, Brevard Community College, Cerro Coso Community College, and Malaspina College, has developed and pilot tested a two-year associate degree curriculum to train solar technicians. It can be duplicated or replicated by other educational institutions for their training needs.

The two-year technician program prepares a person to:

1) apply knowledge to science and mathematics extensively and render direct technical assistance to scientists and engineers engaged in solar energy research and experimentation;
2) design, plan, supervise, and assist in installation of both simple and complex solar systems and solar control devices;
3) supervise, or execute, the operation, maintenance and repair of simple and complex solar systems and solar control systems;
4) design, plan, and estimate costs as a field representative or salesperson for a manufacturer or distributor of solar equipment;
5) prepare or interpret drawings and sketches and write specifications or procedures for work related to solar systems; and
6) work with and communicate with both the public and other employees regarding the entire field of solar energy.

This curriculum consists of nine volumes:

1) an Instructor's Guide for the eleven solar courses, to include references, educational objectives, transparency masters, pre-tests and post-tests, and representative student labs;
2) an Implementation Guide addressing equipment, commitment, and elements to be considered before setting up a solar program;
3) Student Material for each of seven of the core solar courses:
    a) Materials, Materials Handling, and Fabrication Processes;
    b) Sizing, Design, and Retrofit;
    c) Collectors and Energy Storage;
    d) Non-Residential Applications;
    e) Energy Conservation and Passive Design;
    f) Codes, Legalities, Consumerism, and Economics;
    g) Operational Diagnosis.

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USE OF THE STUDENT MATERIALS

The intent of this manual is for student use as a supplement to the instructor's guide for the same course. It contains readings, exercises, worksheets, bibliographies, and illustratons to reinforce the concepts contained within this particular course of study. Each student materials manual is written in a similar format but differs in some details due to the nature of the course and the subject matter covered.

Pretests, posttests, and lab exercise are not contained in this manual. Refer to the instructor's guide for this course to find these items.

Student materials manuals are supplied for seven of the eleven solar courses in this project. The four not included are: Introduction to Solar Energy, Energy Science I, Energy Science II, and the Practicum.

The pagination code is used as follows:

I -- the Roman numeral coordinates with the Roman numeral of the instructor's guide.

S -- the "S" signifies that the page is from the Student Material.

5 -- the Arabic number reflects the specific page within this manual, numbered sequentially throughout.

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

CONSERVATION AS AN ENERGY SOURCE

STUDENT MATERIAL

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

CONSERVATION AS AN ENERGY SOURCE

The purpose of this course is to make two points. First, the wide array of existing cost-effective energy conservation measures represents an enormous - and largely untapped - energy resource. Adoption of these measures can substantially reduce growth in energy use, save money for consumers, and have only slight life-style effects on consumers. In addition, conservation resources can reduce the adverse environmental effects of energy production and conversion, and provide additional time to develop new energy resources.

Second, the best means to obtain these benefits is unclear. Decision-makers lack sufficient information to decide on the proper roles for private enterprise and governments. The best mix of government activities is not known. These activities deliver information on energy use choices; regulate efficiency of equipment, buildings, and motor vehicles; provide financial incentives to purchase energy-efficient systems; and fund research projects on new technologies for energy production.

Revolutions

While it may not be necessary to go all the way back to creation to begin an analysis of energy, more is called for than the usual, "Beginning with the Arab Oil Embargo of 1973 . . .". It is important to realize that there was very little comprehensive energy analysis before that historic event. It is also important to remember that the Embargo happened to coincide with an already planned major price increase. The Arab section of the Organization of Petroleum Exporting Countries (OPEC), playing a role, cut oil production in protest of Western support of Israel in the Yom Kippur War at the same time as OPEC in toto hiked the price of oil by 66%. This event reversed the decline in real energy prices which had prevailed for decades. Oil cost more in the U. S. in 1950 than it did in 1970, and the same was true for electricity. The quadrupling of oil prices which followed the 1973 Embargo snapped energy prices back to their 1950 level. And because the price increase was so abrupt, it focused our attention dramatically on energy and forced us to ask basic questions about our ways of solving problems and our relationship to the rest of the world. Out of it has come a reassessment of traditional perspectives.

Revolutions, as much as anything else, change the way we perceive things. But a revolution need not be a rebellion. Rather, we would hope that the energy conservation revolution will become, in Thomas Jefferson's words, "the extraordinary event necessary to enable all the ordinary events to continue". The invention of writing was such a revolution, for it facilitated the keeping of records necessary for managing trade and agricultural surpluses in the emerging civilizations along the rivers of the Middle East. In Ancient Greece, the revolutionary concept of court-applied justice replaced justice through revenge. But perhaps no revolution has affected the human condition as has the Industrial Revolution. Although the use of machines powered with nonhuman energy spans over many centuries, industry as a mode of life exploded in the aftermath of the Enlightenment of the eighteenth century. Making the Industrial Revolution possible, and perhaps making it necessary, were transformations of agriculture, banking, science, technology, trade, and commerce, all of which helped feed growing millions of people and freed, or uprooted, them to work in the new mills. It took a labor revolution, some would say a rebellion, to correct some of the worst abuses of industrialism, and the world today is divided ideologically over how to correct the remaining problems.

The problems are profound. The industrial world seems to be rushing, lemming-like, to a precipitous exhaustion of oil. Impoverished nations cling tenuously to deteriorating domestic resources and slowly lose their ability to compete for energy in the world market. Events happen so rapidly in the rich countries, and progress comes with such difficulty in the poor, that cause seems separated from effect. Energy, like industry, can be applied both to close and widen the distance. It is a tool, a means, not an end. The labor and environmental revolutions ameliorated some of the worst problems of the Industrial Revolution. So must a new perspective on energy use. Energy conservation can serve as that extraordinary act necessary to maintain the flow of ordinary events.

Energy Transitions

A chart of fuel use in the U. S. throughout its history appears as three overlapping waves. It has gone through two major transitions as it moved from solar energy (wood) to coal and then from coal to petroleum. Wood provided the basic fuel until about 1880 when coal first surpassed it. Interestingly, it was not long before the curve of coal use crossed that of wood that oil was discovered (see Figure 1-1).

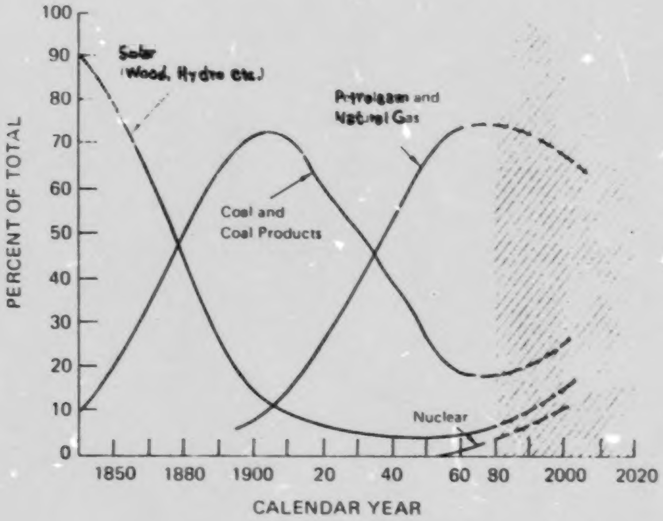

Figure 1-1

The famous "Colonel" Edwin Drake, who died a pauper, first tapped the oil resource in 1859 in Pennsylvania. It was there, much to the chagrin of those who fumble with energy statistics, that the 42-gallon barrel of oil was introduced, and the world's first oil pipeline was laid. Villages like Pithole and Oil City became wealthy boom towns. Oil, which first cost $20 per barrel soon fell to 10¢. The transformation of the face of the Earth by the automobile was expedited when the first drive-in filling station was opened in Pittsburgh in 1913, not by a Pennsylvania oil company, but by one from Texas. where oil had been discovered in 1901. As quickly as they had become boom towns, however, Pithole and Oil City became ghost towns, all their economically recoverable oil exhausted. This portent, along with the shortage-glut cycle first evidenced in the price drop from $20 to 10 cents per barrel, presaged the desperation with which the world seeks and uses oil.

Oil overtook coal as America's primary fuel in the 1940's at about the same time as nuclear energy was first controlled. Enrico Fermi and 49 others assembled a critical mass of uranium and blocks of graphite moderator under the stands of Stagg Field in Chicago in 1942. Enchanted by prospects of boundless and cheap power, nuclear energy became fixed in the minds of many as the major source of energy, and thus energy projections were drawn, in which the curve of nuclear energy use overtook oil sometime in the late Twentieth century. This assumption became so widespread by the 1950's that it reigned as de facto energy policy for the U. S. for three decades.

With the transition from wood to coal, and later from coal to petroleum, the magnitude of demand for purchased energy charged profoundly. Demand rose from slightly more that two quadrillion Btu (quads) per year in 1859 to more than 20 quads per year in 1941. Now the U. S. consumes almost 80 quads per year, three-fourths of which from oil and gas; some projections of turn-of-the-century energy demand would have us using half again that amount. Such auguries call for policies which are the opposite of what is needed. They ignore basic demographic, economic, and environmental factors which make high energy demand futures implausible if not impossible. They also ignore the fact that energy is a means of supplying amenities, not an end in itself. As we make the transition from petroleum to renewable energy resources, we cannot sustain rapid growth in energy use. This transition must therefore be accompanied by a basic transformation in the way we use energy.

U. S. ENERGY RESOURCES

Our increasing demand for energy and the inevitable depletion of conventional fossil fuels make it imperative that other energy sources be developed to supplement and eventually replace these fuels. It appears that such alternate sources will be more sophisticated and costly than those now in use. A number of different sources are receiving attention as possibilities for the future, but substantial scientific and engineering efforts will be required to make these potential sources practical for wide-scale use.

An analysis of present and future energy sources shows that the future use of some energy sources is limited by fuel supplies (e.g., fossil fuels and fission reactors). In other cases, the future use is dependent upon the geographical availability of their sources (e.g., hydroelectric, solar, tides, geothermal, etc.). Still other potential sources are in the late stages of development (e.g., fast-breeder reactors) or are yet to be proven feasible (e.g., fusion reactors).

We can use only that energy which is accessible to us - essentially, energy which is at or very near the surface of the earth. On the basis of this fact we can classify energy sources into two categories: those that provide a continuous influx of energy to the earth's surface, and those that represent stored or potential energy that can be reached from the earth's surface.

Present and Future Energy Sources

During the four centuries that have passed since the invention of the thermometer, no significant changes have been detected in the overall average temperature of the earth's surface and atmosphere. This fact implies that a balance must exist between the total energy that enters the surface environment and the energy stored or lost. This overall balanced system is represented by Figure 1-2.

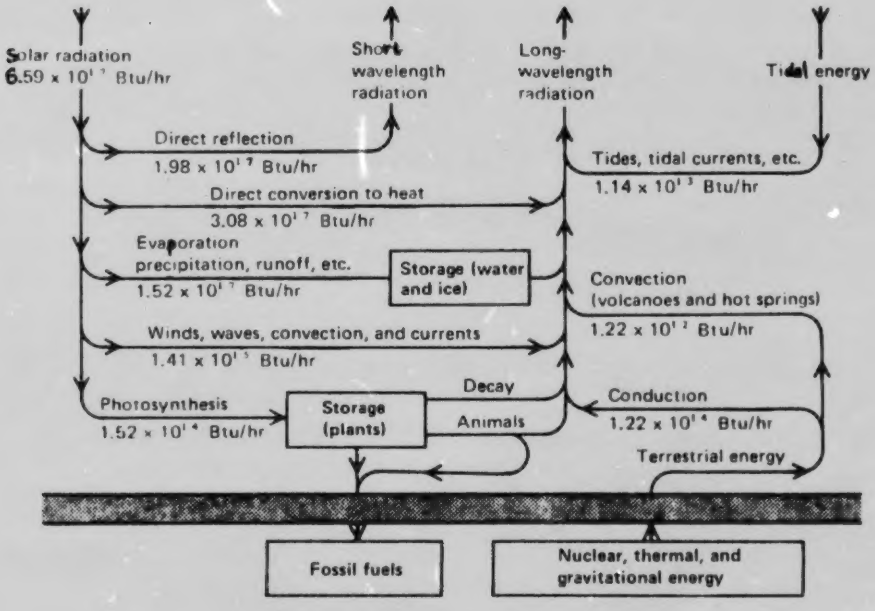
Solar radiation
6.59 x 10^{17} Btu/hr
Short-wavelength radiation
Long-wavelength radiation
Tidal energy
Direct reflection
1.98 x 10^{17} Btu/hr
Tides, tidal currents, etc.
1.14 x 10^{13} Btu/hr
Direct conversion to heat
3.08 x 10^{17} Btu/hr
Evaporation precipitation, runoff, etc.
1.52 x 10^{17} Btu/hr
Storage (water and ice)
Convection (volcanoes and hot springs)
1.22 x 10^{12} Btu/hr
Winds, waves, convection, and currents
1.41 x 10^{15} Btu/hr
Decay
Photosynthesis
1.52 x 10^{14} Btu/hr
Storage (plants)
Animals
Conduction
1.22 x 10^{14} Btu/hr
Terrestrial energy
Fossil fuels
Nuclear, thermal, and gravitational energy

Figure 1-2: Energy Flow Sheet for the Earth

It will be observed that only a tiny fraction of the total energy reaching the earth's surface is stored through photosynthesis. The remainder is converted directly or indirectly into thermal energy at the temperature of the earth's surface. This heat is lost into space in the form of long-wavelength (infra-red) electromagnetic radiation.

The accompanying table, 1-1, contains a list of sources now in use together with some potential sources of energy.

Energy Source	Developmental Status and Prospects for Future Use
Fossil fuels	
Petroleum	Now widely used. Supplies limited – possibly exhausted in 30–40 years.
Natural gas	Now widely used. Supplies limited possibly exhausted in 10–20 years.
Coal	Now widely used. Supplies somewhat limited – possibly exhausted in 300–500 years.
Hydroelectric	Now in use. Number of sites for future development is limited.
Solar	Now in limited use. Practicality somewhat dependent on geography, weather patterns, etc.
Nuclear	
Conventional fission reactors	Now in limited use. Low-cost fuel supply possibly exhausted in 30–40 years.
Fast breeder reactors	Now in late stages of development. Greatly extends potential fuel supply of fission reactors.
Fusion reactors	Feasibility still to be proven. Fuel supply virtually unlimited.
Tides	Now in very limited use. Number of suitable sites for future development is limited.
Geothermal	Now in very limited use. Number of suitable sites for future development is limited.
Wind	Now in very limited use. Number of suitable sites for future development is limited.
Ocean thermal gradients	Not now used. Feasible, but dependent on geography.

Table 1-1.

Projections of Energy Consumption

The continued growth of the use of fossil fuels can occur only for a limited number of years before these resources are exhausted. The implications of compound growth often escape our attention until it is too late. For example, in the U. S. we have used about 100 billion barrels of our domestic oil resources, and there may be 100 billion barrels remaining as recoverable resources. Since we have used oil for about 100 years, it may be tempting to assume that oil should last for another 100 years. But the fact is that the consumption of oil has been increasing at a rate of 5% per year, and the remaining oil could be depleted in another 14 years.

The production of an exhaustible fossil fuel may follow a curve, as shown in Figure 1-3. The production increases, following an exponential curve, passes through a maximum, and declines eventually to a very small quantity as the fuel approaches extinction.

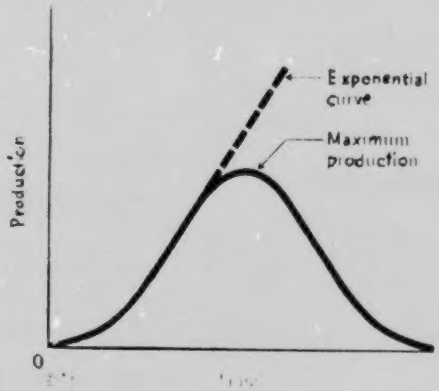

Figure 1-3

Crude Oil: Crude oil has assumed an important and growing role as an energy source in the world. The superior qualities and easy convenience of transportation have made crude oil the preferred fuel since 1920. The result is a U. S., European and Japanese economy heavily dependent upon the availability of oil. The world economy is rapidly approaching the same dependence that industrialized nations now experience.

The U. S. has become increasingly reliant on oil as a primary fuel, as well as a supply for the production of chemicals and other materials. Nevertheless, we understand that oil is finite in supply, and the increased use of oil is causing prices to rise around the world. In 1978, the domestic U. S. oil reserves were 28 billion barrels, and the production was 8.5 million barrels per day. At this production rate, the U. S. has only a 9-year supply of domestic oil. Figure 1-4A is a representation of oil production in the U. S., assuming a total resource of 200 billion barrels. Oil production in the world for two estimated values of total oil resource is shown in Figure 1-4B.

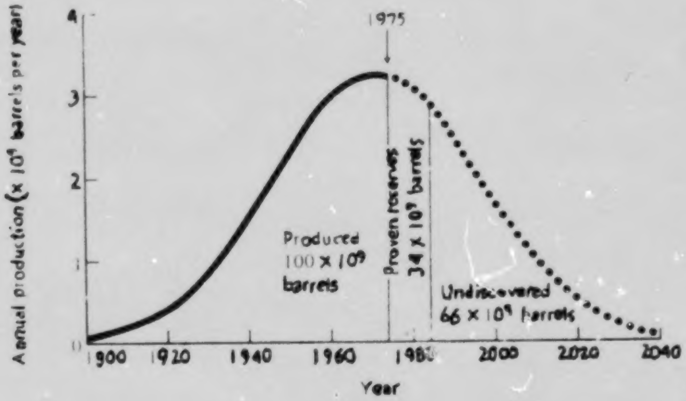

Figure 1-4A.

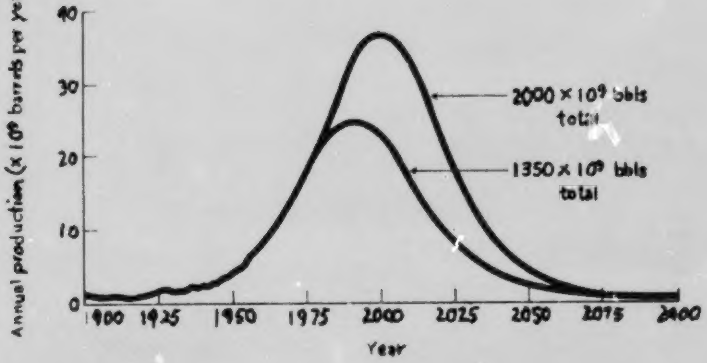

Figure 1-4B.

Natural Gas: Naturally-occurring gas and gas manufactured from coal or oil has been used for lighting, cooling, and heating fuel for over a century. In 1880, the world used approximately 200 billion cubic feet of fuel gas. Almost one century later, the world is using three hundred times that amount of gaseous fuel.

The use of natural gas or gaseous fuel generated from coal came into use in the U. S. after 1890. In 1900, approximately 200 billion cubic feet of gas was used as an energy fuel. Today, about 22 trillion cubic feet of gas is used as a fuel in the U. S., an increase of over one hundred times the amount used 75 years ago.

Natural gas was discovered in the U. S. along with crude oil, and became available as oil wells were developed. Since it was not as easily stored or transported as liquid oil, natural gas was not generally used at first. However, as it was recognized as a valuable fossil-fuel, methods of storage and transportation were developed.

Natural gas can be found with oil in associated gas fields or independently from oil in unassociated gas fields. In the past, some gas has been generated from oil and some from coal. Gas is the cleanest, in terms of pollutants, and most flexible natural fuel, but it is more difficult to store and transport than liquid or solid fuels, especially from one continent to another.

Table 1-2 shows the known reserves of natural gas in the U. S., and the figure is a portrayal of four possible consumption patterns for the use of the natural gas resources of the U. S. The dotted lines show a rapid, but probably unattainable, use of the gas. The dashed lines show a realistic possible use

Year	*Known Reserves (X 10^{12} Cubic Feet)*	*Reserve to Production Ratio*
1960	260	20.2
1965	285	17.5
1967	289	15.5
1970	284	12.5
1972	238	11.5
1973	218	10.5
1974	237	11.1
1975	228	11.4
1978	200	10.1

Table 1-2.

for each of the two ultimate potentials for gas. Case A, Figure 1-5, assumes a total resource of 1500 trillion cubic feet, while Case B assumes a total resource of 2000 trillion cubic feet.

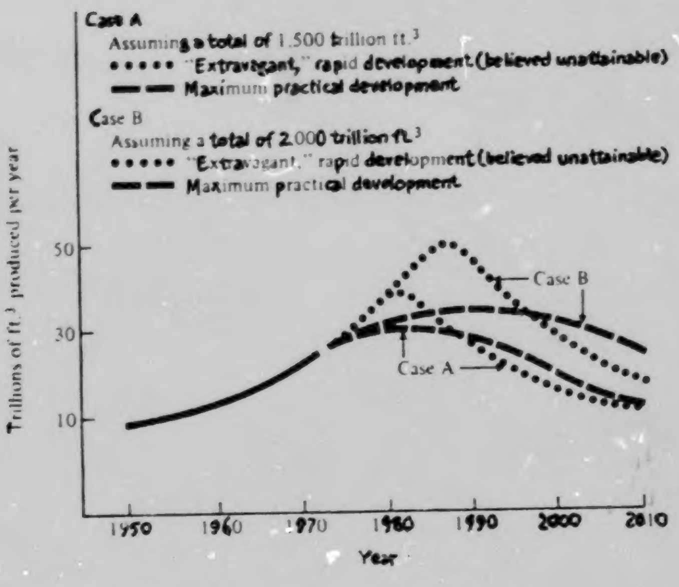

Figure 1-5

Coal: After decades of declining production and increasing disfavor, coal, the most abundant energy resource in the U. S., has been making a strong comeback. It is one of the ironies and dilemmas of our environmentally-aware age that in the future we will use more, not less, of this relatively heavy polluting fuel.

Coal, the fossil fuel extensively used by man, was initially used by the Chinese at the time of Marco Polo or earlier. The use of coal as a major source of energy began in England in the Twelfth Century, and it was deduced that coal could be dug from strata of rock along the cliffs in England, and then from holes sunk to the strata. By the late 13th century, coal smoke was already a source of pollution in London. Coal was used as a domestic fuel, a fuel for lime burning, and by blacksmiths and others for metallurgical processes. By 1750, the annual production in England reached 7 million tons.

Coal was used during the Industrial Revolution for metallurgical processes, glass-making, fuel for railroads, and in general for the steam engine. By 1860, world production of coal reached 150 million tons. From the period 1860 to 1910, annual world production of coal grew from 150 to 1100 million tons, at an annual growth rate of 4.4%.

Coal is actually a family name for a variety of fuels. The beginnings of coal were plants which were accumulated in a bog and became a soggy mass of plant debris we call peat. When peat was compressed over 300 million years ago, it became lignite. Successive invasions of the sea and piling on of layer upon layer of material resulted in the deep burial of the lignite. Deep burial often results in a rise in temperature and an expelling of the moisture, and thus lignite became bituminous coal. In some areas the layers of coal were subjected to large compressive forces, thus resulting in "hard" coal, or anthracite. The main constituent of coal is carbon and hydrogen, with added small granites of sulfur, oxygen, and nitrogen.

The accompanying Table, 1-3, shows the estimated coal resources for the U. S., and Figure 1-6 illustrates the rate of production of coal in the world, for two estimates of total resources. (See following page for Figure 1-6).

Depth of Overburden (Feet)	*Type*	*Resources (Billions of Tons)*	*Energy Reserve ($\times 10^{15}$ Btu)*
100	Strip Coal	140	3.6
100 to 3,000	Bituminous	959	
	Lignite	448	37.0
	Anthracite	13	
3,000 to 6,000	All Types	337	8.8
6.000 to 9,000	All Types	1,313	34.1
		3.210	83.5

***Note:** Current mining methods are not economical below depths of 1,000 feet*

Table 1-3.

Uranium: The nuclear energy industry began on December 2, 1957, with the operation of the first commercial (fission) reactor at Shippingport, Pennsylvania. The industry has grown steadily since then, and at the end of 1973, 42 plants were licensed to operate, and all but two were producing electricity.

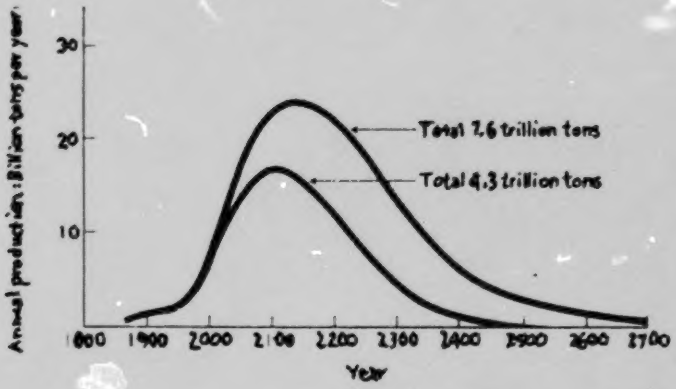

Figure 1-6

Another 56 units were in various stages of construction, and 56 more were under review for construction permits. The 40 units actually operating at the end of 1973 represented 5.5% of the total electrical power generating capacity of the U. S. At that time it was estimated that 33% of all electricity generated in this country in 1985 would come from nuclear power plants, and by the end of the century, the nuclear contribution was projected to increase to 60%.

All fission reactors ultimately depend on uranium-235 as a fuel. Uranium-235 comprises only 0.72% of naturally occuring uranium ore. Even though plutonium-239 and uranium-235 are fissionable, they must be produced in breeding reactions that originally begin with uranium-235. These produced fuels can be used in the same way as uranium-235 to breed new fuels. U. S. domestic resources of uranium are given in Table 1-4, which is shown on the following page. Figure 1-7, shown on the following page, illustrates how the development and use of breeder-reactors is expected to influence future demands for uranium. This figure shows projected domestic uranium oxide requirements on the basis of three situations:

1. only light water reactors (LWR) and high-temperature gas-cooled reactors (HTGR) are used;
2. liquid metal fast breeder reactors (LMFB) are introduced by 1986; and
3. liquid metal fast breeder reactors are introduced by 1990.

DOMESTIC RESOURCES OF URANIUM IN THE U.S.

		(Thousands/Tons)	
Cost	*Reasonably Assured*	*Estimated Additional*	*Total*
up to \$20/kg	315	960	1,275
up to \$30/kg	420	1,500	1,950
up to \$60/kg	600	2,900	3,500

Source: M. C. Day, "Nuclear Energy: A Second Round of Questions" *Bulletin of the Atomic Scientists*, Dec. 1975, pp. 52-59.

Table 1-4.

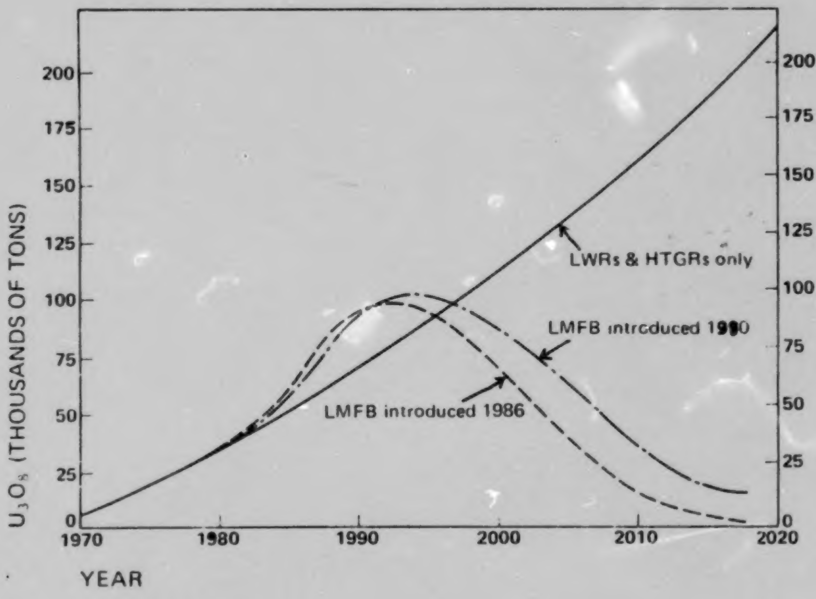

Figure 1-7

Breeder use significantly increases uranium oxide demand for a time (1986-94) because of the requirement for fertile uranium-238 compounds (breeder fuel). The pronounced decrease in uranium demands after the middle 1990's when breeders are used is a dramatic representation of their efficiencies. As much as 70% of the fission energy of natural uranium is recovered by breeders, while light water reactors are capable of extracting only about 2%

Hydroelectric Energy: Falling water from natural or regulated streamflow has been used as a source of useful energy for many centuries. The waterwheel, initially used in the First Century, B. C., was the first major source of energy that was not related to human or animal muscle power. By the sixteenth century, the waterwheel was western Europe's most important energy source. Steam engines, the first really mobile energy sources, had replaced most waterwheels by the middle of the nineteenth century. However, interest in water power was renewed during the 1850-1900 period as a result of the invention of the versatile and efficient hydraulic turbine. This device had a much greater maximum power output than waterwheels. Numerous types of improved turbines have been developed since the first one dedicated to generating electricity was installed on the Fox River in Wisconsin in 1882. Today, the generation of hydroelectricity is common in many parts of the United States.

The gross consumption of hydroelectric energy in the U. S. during 1973 was an amount equal to 3.9% of the total energy used during the year. The total hydroelectric generating capacity is projected to double again in the next 25 years. However, hydroelectric growth rate during the projected period will be less than the growth rate of total energy demands resulting in hydroelectric meeting only 3.1% of the total U. S. demand. Although hydroelectric energy is a traditional energy source, it has a limited potential for expansion. Table 1-5, which appears on the following page, shows the hydroelectric potential of the U. S.

U. S. ENERGY DEMAND

The operation of our technological society depends upon the production and use of large amounts of energy. Many of the world's present problems are closely related to problems of energy distribution, dwindling fossil fuel supplies, and environmental effects of various methods of energy production and usage. Energy is not only a commodity, it is also an idea - an intellectual concept which stands out in the history of modern scientific and engineering thought.

Conventional Capacity (thousands of megawatts)

Region	Total Potential	Developed Capacity	Undeveloped Capacity	Percent Developed
New England	4.8	1.5	3.3	31.3
Middle Atlantic	8.7	4.2	4.5	48.3
East North Central	2.5	0.9	1.6	36.0
West North Central	7.1	2.7	4.4	38.0
South Atlantic	14.8	5.3	9.5	35.8
East South Central	9.0	5.2	3.8	57.8
West South Central	5.2	1.9	3.3	36.5
Mountain	32.9	6.2	26.7	18.8
Pacific	62.2	23.9	38.3	38.4
Alaska	32.6	0.1	32.5	0.3
Hawaii	0.1	–	–	–
Total	179.9	51.9	128.0	

Table 1-5: Hydroelectric Potential of the United States

The problem of energy use and availability is common, to a greater or lesser extent, throughout the world. While the industrialized nations of Europe and North America depend heavily upon fossil fuels for their industrial processes, the developing nations also desire to increase their technological capabilities and thus their use of energy in its various forms. In addition, due to the unequal distribution of fossil-fuels throughout the world, profound economic and political issues are associated with energy use.

Energy, the ability to accomplish physical work, is featured mainly as an input of economic processes and as an intermediate good. It is rare to find energy demand for its own sake. Energy is usually valued as an input in some process of production or utilization which results in a final product.

Energy Consumption

People have adapted energy to a wide range of personal and industrial uses. The most significant personal uses are for cooking, comfort, heating and cooling, illumination, transportation, hot water, refrigeration, and communications. These uses extend far beyond the bare essentials for life, and they provide increasingly for comfort and convenience. The most significant industrial uses are for heat and power.

Nonindustrialized societies still are heavily dependent on the traditional energy sources - local solar energy that is made available through the agencies of food, work-animal feed, nonmineral fuels (wood, dung, and agricultural wastes), wind power, and direct waterpower. Energy consumption per person is very small, only a few times the food energy required to sustain life.

In contrast, industrialized societies use large quantities of fossil fuel (coal, oil, and natural gas) and electricity, and consumption of energy per person is as much as a hundred times the energy contained in food. Fossil fuels and hydropower provide a twelvefold increase in energy for the industrialized regions, compared with a twofold increase for the nonindustrialized regions. When one speaks of energy in an industrialized society, one ordinarily refers only to energy for heat, light, power and communication, leaving aside the energy content of food.

Fairly accurate records exist for the overall energy consumption of the United States, particularly in recent decades, since it is known how much coal, oil, natural gas, hydropower, nuclear power, and other forms of energy are consumed each year. But the records are incomplete with respect to energy consumption for most specific purposes or end uses. There are good records for some, for example, energy in the form of gasoline for automobiles. Suppliers know how much energy in the form of electricity is delivered to each home, but the proportions that are used for cooking, heating, light, refrigeration, television, and other purposes can only be estimated.

Table 1-6 shows the approximate pattern of energy consumption in the United

	Segment of the Economy			
End use	Industrial	Residential and personal	Commercial and public	Total
Transportation	1	16	9	26
Comfort heat	2	11	7	20
Process steam	16	—		16
Direct heat	11	—		11
Electric drive	9	—		9
Lighting	1	1	3	5
Hot water	—	3	1	4
Air conditioning	—	1	2	3
Refrigeration	—	1	1	2
Cooking		1		1
Electrochemistry	1			1
Other (mostly electric)	—	1	1	2
Total	41	35	24	100

Table 1-6.

States during the mid-1970's. Energy can be transformed to electricity before it is used, as for lighting and for powering machine tools in industry. Wherever this is done, the table shows the energy content of the fuel required to make the electricity. There is no doubt that the major features of the nation's energy consumption pattern are correctly portrayed in the table, but individual percentage entries are probably not accurate to better than one percentage point. Wherever there is a dash in the table, the energy consumption for that segment of the economy is estimated to be less than 1/2% of the nation's total consumption.

Energy flows through the United States economy in the mid-1970's are shown in Figure 1-8. The flow of energy is from the nation's major energy sources (left), which is converted for useful applications by means of various energy conversion facilities (middle), to useful applications given in the preceding table (right), and unavailable energy (bottom). The conversion includes furnaces, heaters, and stoves for generating heat, internal combustion engines for generating power, and steam engines and other heat engines for generating

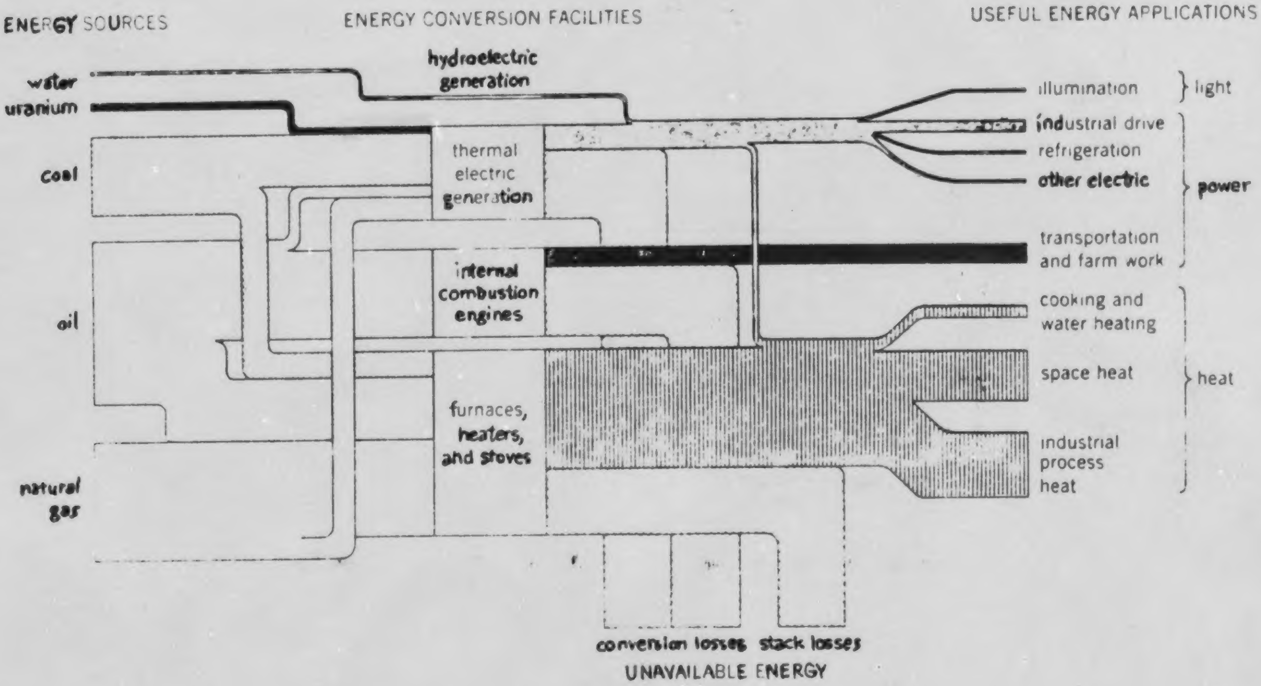
ENERGY SOURCES
ENERGY CONVERSION FACILITIES
USEFUL ENERGY APPLICATIONS
water
uranium
coal
oil
natural gas
hydroelectric generation
thermal electric generation
internal combustion engines
furnaces, heaters, and stoves
illumination
light
industrial drive
refrigeration
other electric
power
transportation and farm work
cooking and water heating
space heat
heat
industrial process heat
conversion losses
stack losses
UNAVAILABLE ENERGY

Figure 1-8

power in electric power plants. In the process of conversion, there is a flow of unavailable energy in the form of low-temperature heat which is lost up stacks and chimneys and is also lost in the conversion of high-temperature heat to mechanical power.

Trends in Energy Consumption

A hundred years ago it took about the same amount of energy to heat a house as it takes today. It took about half as much energy to feed the family horse as it now takes to power the family car. It took about the same amount of energy to cook a meal. People use more energy today, partly because they drive more and partly because they work in offices and factories instead of in open fields, but they still only use about 2-1/2 times as much per person.

Figure 1-9A shows how energy consumption per person grew between 1850 and 1975. It has been growing very rapidly in recent years. If this growth were to continue, the supplying of the required coal, oil, gas and uranium would create a strain. The supply problem would not be so serious if energy consumption per person were to level off.

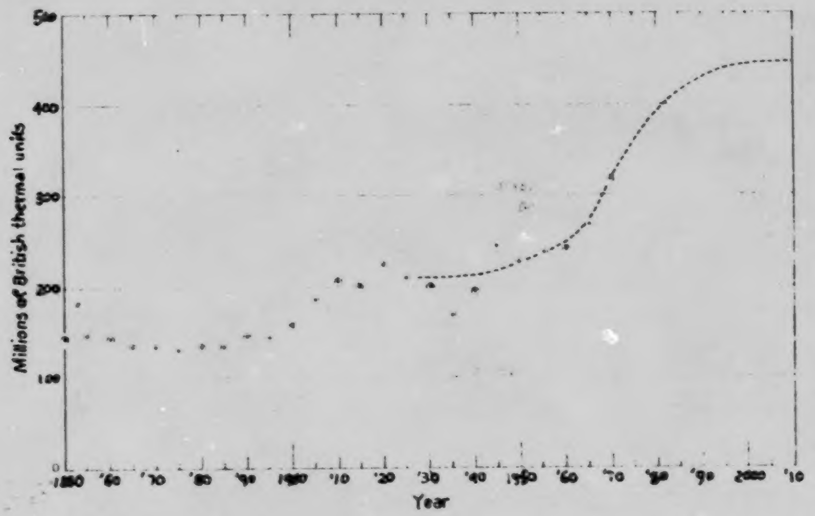

Figure 1-9A: Per-capita energy consumption in the United States, 1850-1970, and projected to 2010. Annual energy consumption is projected to level off at about 450 million Btu per person by the end of the century.

Personal automobile driving is likely to level off by the time every adult has a car to drive. Figure 1-9B shows how the average number of cars per adult has increased from practically nothing in 1910 to about 0.75 car per adult in the 1970's, and then projection to 2010.

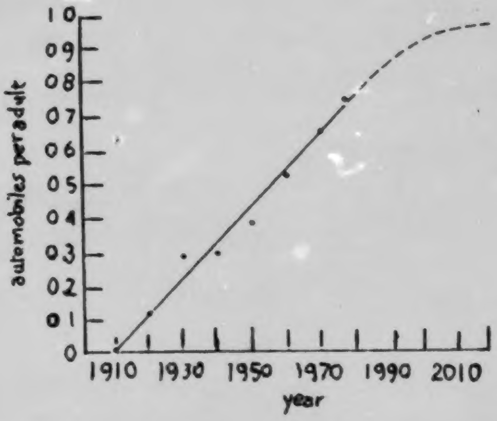

Figure 1-9B: Average number of automobiles per adult (age 18 and over) in the United States, 1910 to 1977, and projected to 2010.

Job-related energy consumption has gone up as more factories and offices have been built. The fraction of the population employed in factories and offices amounted to only about 10% in 1850, but it rose to about 30% a hundred years later. Since 1960, it has risen to about 36% as more and more women have taken jobs outside the home. This trend has a natural limit at about 45% of the population, when everybody of working age will have a job in an office or factory. Growth of the nonfarm labor force will slow down to match overall population growth, and growth of job-related energy consumption will tend to do the same.

As affluence increases, partly through more jobs per family, more energy tends to be consumed in the home, mostly for hot water and for comfort heating and cooling. When these basic energy needs are met, energy consumption in the home rises more slowly with increased affluence.

It is anticipated that overall per capita energy consumption may level off. The conservation movement is a welcome expression of people's desire to limit and control energy consumption; indeed, the vitality of the movement may be a symptom, as much as a cause, of the growing achievement of sufficient energy for personal use in society.

The pattern of energy consumption may change in still other ways over the next several decades. Progressive electrification of energy ucage is likely to continue. This is the best way to make use of nuclear energy, and improved technology can be expected to increase the efficiencies of electric power generation and application, so that electricity will be chosen more often over direct fuel combustion. There is a potential for limited use of solar power, primarily for supplying hot water and for comfort heating.

A possible future pattern for the flow of energy through the United States economy is shown in Figure 1-9C. Compared with the present, as shown previously, uranium and coal may provide more of the energy. The efficiency of conversion facilities may improve. Heat pumps, by drawing heat from the air, may augment the effectiveness of electrical heat. More efficient use of energy, as projected in Figure 1-9C, combined with a leveling off of per capita energy consumption and slower population growth, will tend to moderate the nation's overall energy consumption.

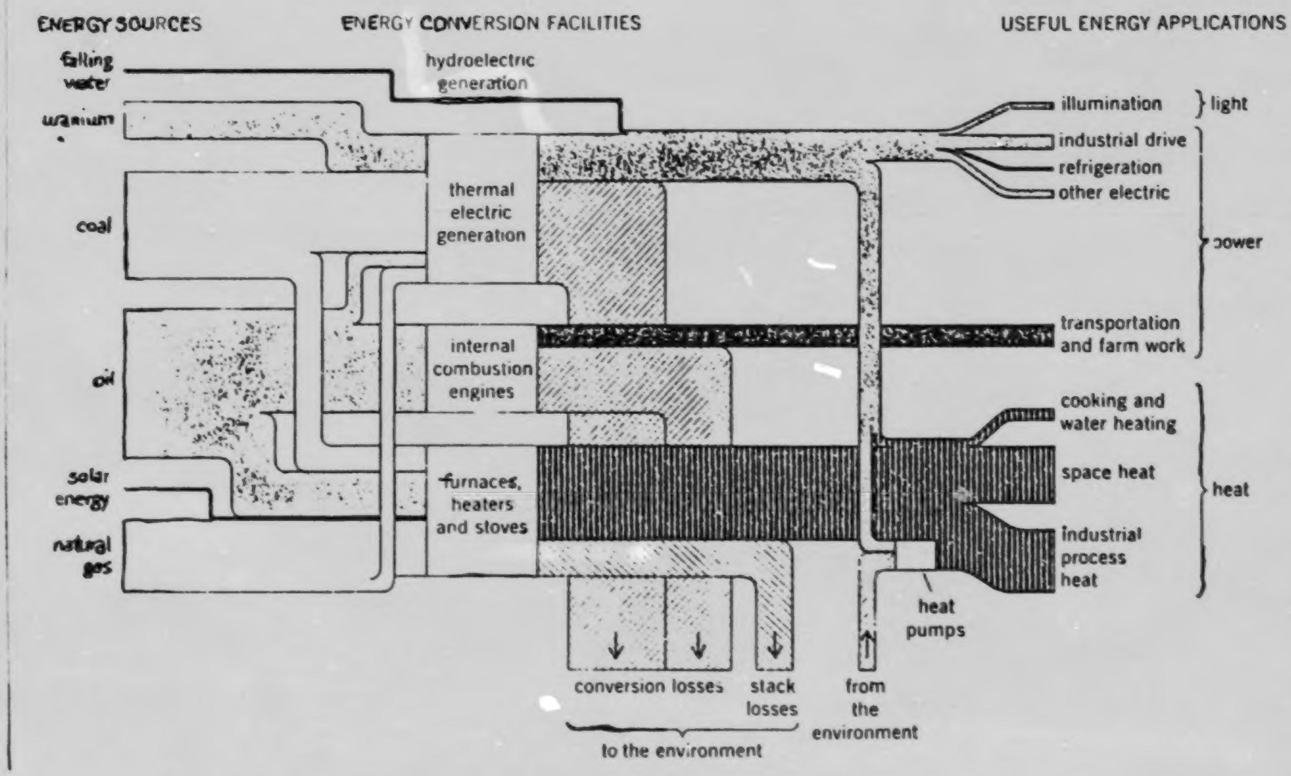
ENERGY SOURCES
ENERGY CONVERSION FACILITIES
USEFUL ENERGY APPLICATIONS
falling water
uranium
coal
oil
solar energy
natural gas
hydroelectric generation
thermal electric generation
internal combustion engines
furnaces, heaters and stoves
illumination
light
industrial drive
refrigeration
other electric
power
transportation and farm work
cooking and water heating
space heat
industrial process heat
heat
heat pumps
conversion losses
stack losses
to the environment
from the environment

Figure 1-9C.

CONSERVATION ISSUES

Few concepts are interpreted as diversely as energy conservation. Because world energy prices changed abruptly in 1973 and the simultaneous embargo of oil engendered such sudden responses, most people have come to associate conservation with those curtailment actions that had to be taken quickly to reduce demand. Conservation strategists, however, employ a much broader notion of conservation, one which allies the term with "wise use". Three major strategies are implied by wise use:

1. obtaining higher efficiency in energy production and utilization,
2. accommodating behavior to maximize personal welfare in response to changing prices of competing goods and services, and
3. shifting from less to more plentiful energy resources.

All three strategies emphasize technological change that allows smaller energy requirements for a given amenity level. In a real sense, then, energy conservation means substituting ingenuity for energy-intensive living. The main principle guiding the amount of energy conservation desired is the comparison of the real price of energy with alternative goods and services. Conservation is thus viewed by the practitioner as a means of enhancing perceived welfare and as a means of leaving society better off than it otherwise would be.

It follows that waste, too, is an economic term. To fail to make changes which do not affect lifestyle, that is, which do not affect the level of amenity obtained from a given energy-consuming service or product, and which have an acceptable rate of return on investment, is wasteful. Conservation is the sum of those measures which simultaneously save energy and are economically justifiable.

Providing the nine basic amenities listed in the table on the following page requires almost two-thirds of the energy used in the U. S. Thus, while it might seem that, in order to use less energy we will have to sacrifice some of these essentials supplied by energy, such is not the case. The energy required to heat existing buildings, for example, can be cut by more than half with economical weatherization features. Automobiles can be built to obtain 40 miles per gallon at no extra total cost to the consumer or sacrifice in safety, and with little loss of comfort and performance. The energy productivity of chemical manufacturing can be improved 20 to 40% by the end of the century. Only in emergencies must we curtail our use of energy.

Major End Uses of Energy In the U. S.

End Use	Percent of Total
Space Heating	16
Automobiles	13
Chemicals Manufacture	9
Iron & Steel Manufacture	4
Lighting	4
Air Conditioning	4
Water Heating	4
Paper Manufacture	4
Trucks	6
Subtotal	64
Other	36
Total	100

How Does the U. S. Use Its Energy?

The output uses of energy in this country are shown schematically in Figure 1-10, which appears on the following page. It is instructive to combine the various uses in this manner, since it clearly shows that there are three primary use segments: Buildings, Industrial, and Transportation. One-third of the total use occurs in the building segment and this is dominated by comfort conditioning, an area where conservation measures can yield significant returns.

Energy Conservation

Energy conservation, probably the least understood element in debates over United States energy policy, refers to practices and measures that increase the efficiency with which energy is used in all sectors of the economy. Increased efficiency implies an improvement in overall productivity - doing more with less.

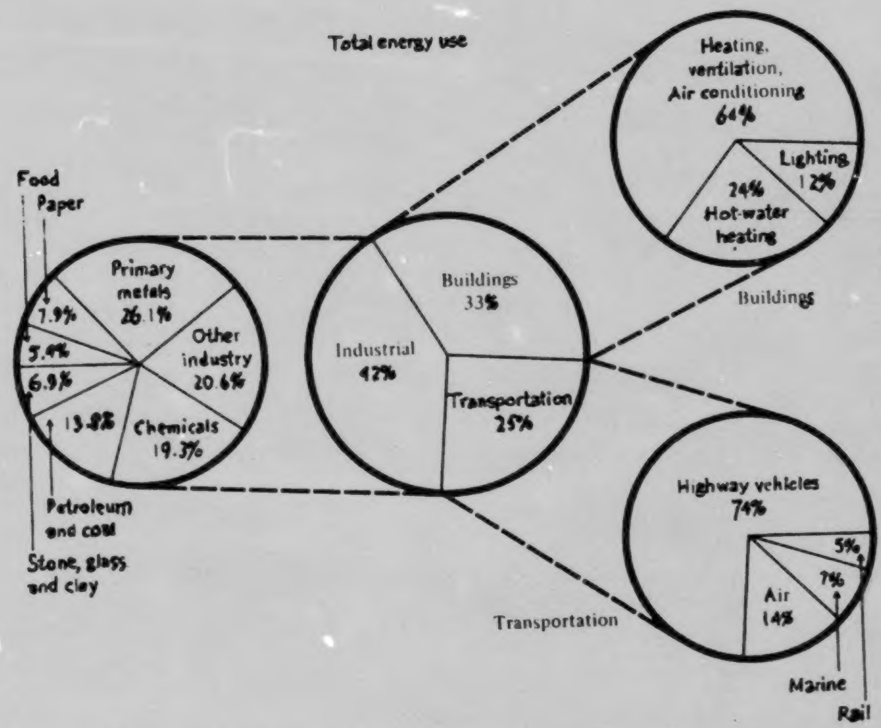

Figure 1-10: The Uses for Energy in the U. S.

It is important to distinguish between energy conservation and energy curtailment. Curtailments (for example, Sunday closings of gas stations or mandatory reductions in winter temperature settings in commercial buildings) involve immediate short-term, mandatory reductions in energy use, and occur primarily because of policy failures to deal with long-term problems. Thus, curtailments may reduce economic output and well-being; energy conservation generally increases economic productivity and improves well-being.

Some conservation practices (for example, lower indoor temperature settings in winter), when compared with historical patterns, imply doing with less. However, when considered in the context of present and future higher fuel prices and reduced fuel availability, these measures are more attractive than the alternatives.

Energy Conservation In Existing Buildings

Most of America's buildings are not efficient consumers of energy. It is thus in the interest not only of individual building-owners but of national security and economic strength that a concerted program of energy conservation be implemented as widely and rapidly as possible.

In fact, such a program is already underway and an Architects and Engineers Guide has been issued which provides the methodology for developing and implementing a successful building energy management program. The methodology consists of a seven phased program which should be done in sequence. The various phases are summarized below, however, it is first necessary to make a distinction between an energy management program and an energy study.

An energy management program, as the term implies, is a systematic, on-going strategy for controlling a building's fuel-consumption patterns in such a manner as to reduce the waste of energy and dollars to the absolute minimum permitted by the climate in which the building is located, as well as by the condition of the building its functions, occupancy schedules, and other factors. In short, an effective energy management program establishes and maintains an efficient balance between a building's annual functional energy requirements and its annual actual energy consumption.

An energy study, on the other hand, is a crucial early step in the fashioning of a full-scale energy management program. It is the study which produces the data on which such a program is based. The energy study begins with a detailed, step-by-step analysis of the building's energy-use factors and costs. The energy study can be and often is, the most important step in the energy management program.

It is now appropriate to discuss the actual phases involved in developing and implementing a successful energy management program.

Phase One--Select The Energy Management Team: Once a building owner has agreed to consider an energy management program for his or her facility, it is advisable to assemble and activate an energy management team, even though the nature and extent of the energy management program will not be known until the subsequent study has been completed. A typical energy management team consists of: (1) the building owner and/or manager or representative; (2) the building accountant; (3) the building engineer or maintenance supervisor; (4) a representative from each major tenant-firm or division in the building, particularly when such divisions correspond with different "functional areas" (e.g., data processing, typing pool, executive suite, parking garage, restaurant, floors or departments in a department store, mailing room, etc.); (5) the professional energy consultant. To these may be added, when possible and appropriate, the original building architect and engineer and a representative from each of the major fuel and utility companies serving the building.

Part of the idea in assembling this team is to achieve as complete a cross-section as possible of persons having direct first-hand experience with the thermal performance and characteristics of the building. Among the early functions of the team is to provide a body of specific suggestions and ideas for reducing the building's energy consumption. Later, when the energy management program is being implemented, the team will be responsible for helping to win the cooperation of other employees and tenants in the building. (This effort may be enhanced by setting specific "energy conservation goals" for different floors, departments, divisions, etc., perhaps on a friendly competitive basis.)

At any rate, the energy consultant should solicit and record ideas from the team, along with such data as utility bills and construction records. Finally, in preparation for conduting the energy study, the energy consultant might want to break out a smaller component of the team to assist directly with the study itself. This "energy study sub-group" will typically include the building accountant and engineer, plus what other persons may be appropriate.

Phase Two--Survey the Building: This phase of the program actually consists of several major sub-phases, including an audit and graphic display of the building's percent energy consumption, gleaned from fuel and utility bills, as well as a physical survey of the shell, interior spaces, power and distribution systems of the building itself. It is during this survey phase that the energy consultant begins to note potential energy conservation opportunities, which may or may not be supported by additional evidence and cost-benefit analysis.

Phase Three--Tabulate Present Energy Use: A thorough survey of the client's building will result in two sets of data pertaining to the building's energy-use. One of these will be a detailed accounting of fuel and electricity consumption on an annual basis, as determined from utility statements. The other will be a detailed breakdown of the energy consumed by individual zones ("functional areas") and features of the shell and mechanical systems of the building itself, as determined from the physical inspection. The latter items are called "energy-users". A total of the energy consumption represented by each "user", projected on an annual basis, should correspond with the total consumption of the building as inferred from the utility bills. (Substantial discrepancies between the two totals will necessitate a review and adjustment of preceding calculations.)

These totals, along with the calculations and subtotals from which they are drawn, will account for all the energy consumed by the building and pinpoint where and how that energy is used.

Phase Four--Identify Energy Conservation Opportunities: At this point, the energy consultant will have established not only a comprehensive picture of the building's present energy use but a tentative list of energy conservation opportunities (ECO's), compiled during the execution of Phases One-Three above. Now the consultant may systematically analyze the feasibility of these tentative ECO's, along with others which may be applicable.

A major requirement here is that potential ECO's must be analyzed in such a manner as to account for thermal and functional interrelationships between the various loads and features of the building's shell and energy systems (e.g., the effect of a reduction in lighting levels on heating and cooling loads).

Phase Five--Summarize Costs and Benefits: Having identified, grouped, and determined the feasibility of all potential ECO's in the client's building, the energy consultant must now assess the impact of those ECO's, both singly and collectively, on the building's future energy use. In other words, how much energy will be saved by the implementation of each ECO, each group of ECO's, and all the ECO's combined, as measured against the building's present energy use?

Once these potential energy savings have been established, they can be converted to dollar savings, thus providing the basis for a cost-benefit analysis of the potential ECO's, including a comparison of implementation costs (initial dollar investment required for each potential ECO) with projected savings per year and estimated "payback" periods. This information is then submitted to the owner and/or the energy management team in the form of a list of conclusions and recommendations by the energy consultant. It is on the basis of this last step in the energy study that decisions are made on the scope, cost, and extent of the energy management program to be implemented.

Phase Six--Set Goals: Most energy management programs are best designed and accomplished on the basis of specific energy conservation goals which the team will establish after having decided on the scope of the program itself, including the implementation of ECO's. These goals can and should be expressed in a variety of ways, depending on the nature of the building in question, the types of ECO's to be implemented, the types of activity and personnel housed by the building, seasonal fluctuation in load demand, etc. As suggested above, for example, the desired goals for the entire building can be broken down according to zones, divisions, floors, departments, and/or "functional areas", with appropriate employees or staff persons assigned the responsibility of helping to achieve those goals.

Not only annual goals should be set, but seasonal and monthly goals as well, especially in climates with distinct seasonal weather variations or in buildings with marked seasonal fluxation in activities and occupancy such as schools which often close for summer and other holidays. The setting of these goals may well be accompanied by the installation of energy-metering and monitoring equipment in each location where specific goals have been assigned (as discussed in Phase Seven below), so that the persons involved may keep a "running account" of their progress toward the desired goals. This can then be adjusted for heating and cooling degree days and changes in operating hours for comparison to the base goals established. Care should be taken, finally, that the goals imposed are not so ambitious that they can't be met by the persons responsible for them. In this regard, it it often prudent to establish more modest goals for the first month or two, see those goals accomplished, and then set progressively higher goals until the maximum energy reductions are being accomplished regularly. The goal thereafter, of course, is to maintain those reductions.

(NOTE: Another approach to "energy conservation goals" is to establish a specific energy budget for the building in question, with proportionate budgets assigned to the various zones or "functional areas" to be monitored during the energy management program. Consequently, the terms "energy budget" and "energy goals" are used more or less interchangeably.)

Phase Seven--Implement and Monitor the Program: The requirements of this phase of the program will obviously depend on the scope of the program iteslf. Assuming that a consultant is retained, it will typically be the consultant's responsibility to prepare working drawings and specifications for all proposed construction work and to help the owner in taking competitive bids. Once the appropriate contracts are signed, usually under the supervision of the owner's attorney, the energy consultant generally will oversee all construction work and certify payments to contractors.

Upon completion of the contracted alterations, the energy consultant will manage or initiate some or all of the following post-construction services (in addition to helping establish an energy budget or set of goals as discussed above):

1. Develop specific operating programs and schedules to monitor and control the operating systems for maintaining the environmental conditions conserving the maximum amount of energy, reducing operating costs, and utilizing manpower most effectively.

2. Train operating personnel and supervise the educational program to acquaint the building occupants with new operating conditions and goals.

3. Supervise the preparation of log books, which record all changes, energy use on a monthly basis (by sub-systems), and costs, in order to document the program and assure continuity of effort. Monthly consumption, adjusted for degree days, cooling hours, and operational changes, will indicate the effectiveness of the current program.

4. Install suitable monitoring procedures to record the performance of modified equipment or procedures. These, where appropriate, may include:

    a. Institute maintenance of equipment operation logs to identify hours of operation and responsibility for start-stop.

    b. Install elapsed time meters to record hours of operation of prime movers.

    c. Install electric watthour meters to record usage of electric energy for specific operations or departments.

d. Install fuel meters to record consumption of fuel for specific operational purposes.

e. Install Btu meters, steam flow meters or condensate meters to identify heat input or output of processes of building environmental apparatus.

f. Recording thermometers may be installed to verify performance of critical automatic temperature controls.

g. Recording ammeters may be used to monitor relative load changes in electric prime movers and power distribution feeders.

5. Develop reporting procedures and summaries to monitor the operating and maintenance personnel execution of energy conservation program elements. Daily, weekly, and monthly logs of equipment use, meter readings and performance evaluations should be summarized and reported to operating personnel. Continued reference to performance goals and actual achievement is necessary to sustain interest and reward successful effort and skill at the level at which operating decisions are actually made.

   a. Start-stop equipment logs and elapsed time meters should be totalized monthly and performance compared to the energy budget allocation.

   b. Submeters on electricity, fuel, steam, condensate, chilled water, hot water, etc., should be totalized monthly and performance compared to the energy budget allocations.

6. Prepare comparative statements of energy use semi-annually to show the actual purchases of electricity and fuel compared to the energy budget and the adjusted record of energy purchased in the past. Graphic presentations may provide a continuing synopsis of the effects of energy conservation programs.

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ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

ENERGY CONSERVATION AND HUMAN COMFORT

STUDENT MATERIAL

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

ENERGY CONSERVATION AND HUMAN COMFORT

HUMAN COMFORT

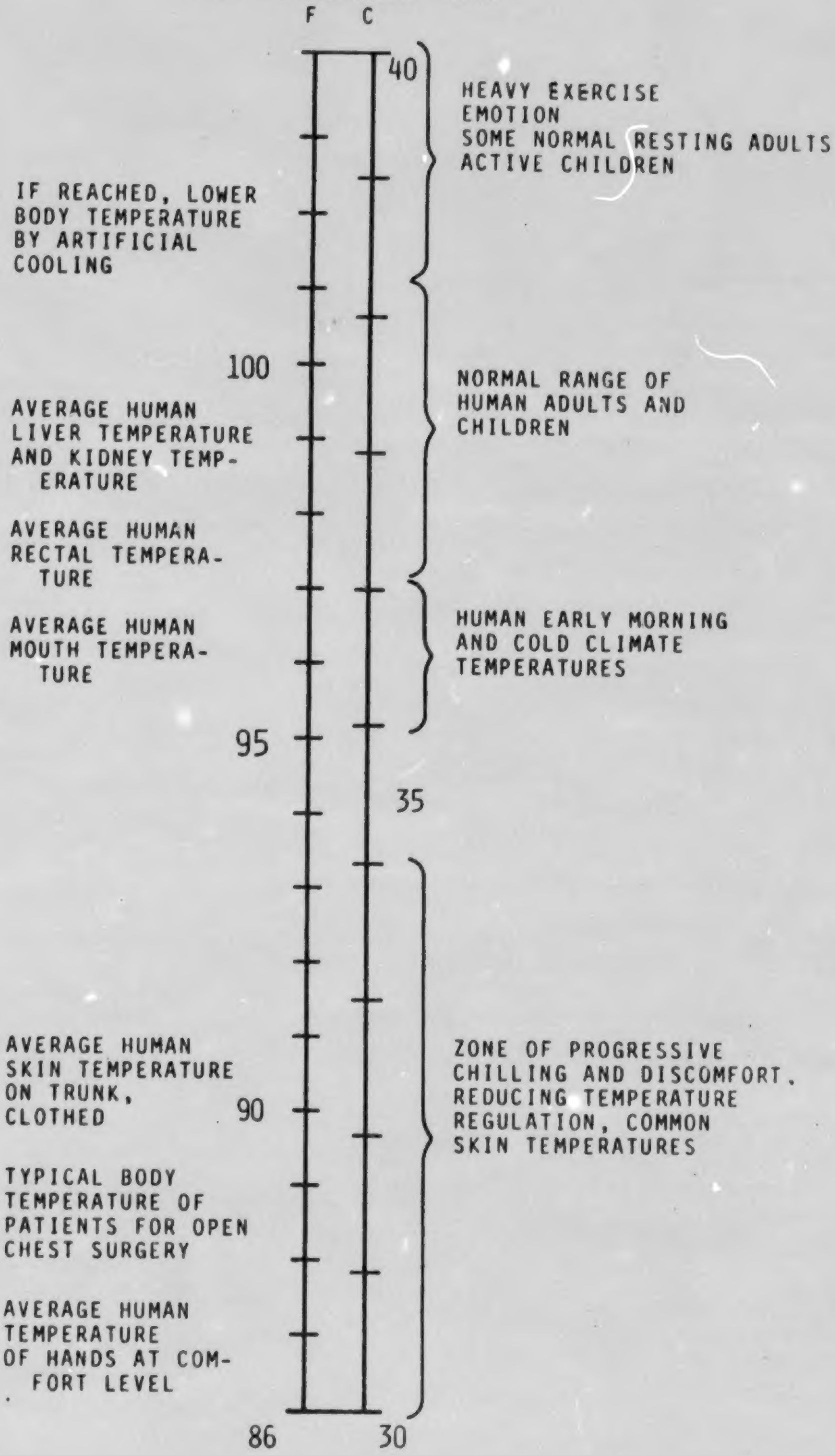
Like all forms of matter - living or non-living - human beings contain internal energy called thermal energy. However, unlike non-living forms of matter, human beings must, if they are to live and be active, possess a relative, constant amount of thermal energy; and **body** temperature of humans must, therefore, remain within a rather narrow range. An understanding of the way the body maintains this temperature helps in understanding the way the air-conditioning process helps keep the body comfortable.

The total heat content of the body can be determined by the net difference between the heat produced and the heat lost, and it is essential that heat loss and heat gain be controlled for both human comfort and survival. In the human body, heat production and heat loss are governed by various physiological mechanisms, and for body comfort, all of the heat produced must be given off by the body. Since the body produces more heat than it needs, heat must be constantly given off or removed. Since heat is lost from the surface of the body by radiation, conduction, convection, and water evaporation, in time its thermal energy content would be dramatically reduced, if there were not some provision for providing the body with needed thermal energy. How does the human body get needed thermal energy? Thermal energy in human beings is derived from food consumed. Heat control can be accomplished through food and water intake, proper clothing, variations in physical activity, and maintenance of appropriate environmental conditions indoors.

Body Temperature

The normal temperature of the human body is 98.6° F. This temperature is sometimes called subsurface or deep tissue temperature, rather than skin or surface temperature. Most individuals will suffer convulsions if their body temperature rises to 106-107° F. However, it is important to realize that, even in a "perfectly normal" individual, the temperature is not the same in all parts of the body. The temperature of the brain and arterial blood may be kept at 98.6° F, while the temperature of the arms and legs may be considerably lower. The human comfort can be summarized with a body temperature chart as shown in Figure 1-11, which appears on the following page.

BODY TEMPERATURE CHART



Body Heat Production

All food taken into the body contains heat in the form of calories. The nutritional Calorie is defined as the amount of heat required to raise one kilogram of water by 1° C. The energy that is contained within the chemical bonds of the food consumed will provide structural components out of which the body is made, and energy that is necessary for the proper functioning of the body. Food consumed and not used as structural components of the body, or converted into energy to maintain the body's vital activities and temperature, will be converted into fat and stored in a special tissue called adipose tissue (fat tissue) that is usually found under the skin.

As the Calories are taken into the body, they are converted into energy. This energy conversion process generates heat. All body movements also add to the heat generated by the conversion process and use up the stored energy. Individual caloric requirements will vary according to age, sex, height, weight, body surface area, emotional state, environmental temperature, circulating levels of certain hormones, and other factors.

Food, in releasing energy in the form of heat, is to the human body what oil is to a furnace. Depending upon the type and quality of food ingested, four to six hours are required for its digestion and accompanying release of thermal energy. Carbohydrates (candies, bread, sugar) release their thermal energy quickly. Fatty foods (fatty meats, dressings, fried foods), however, release greater quantities of thermal energy over a longer period. Proteins also release thermal energy at a slower rate than carbohydrates. The approximate caloric values of some common foods are given in the accompanying table, Figure 1-12, which is shown in the following pages.

APPROXIMATE CALORIC VALUES OF SOME COMMON FOODS

CALORIC VALUES ARE GIVEN IN NUMBERS THAT ARE MULTIPLES OF FIVE TO SIMPLIFY THE ESTIMATING OF TOTAL CALORIES.

FOOD	SIZE OF SERVING	APPROXIMATE CALORIES
FOODS CLASSED AS LARGELY CARBOHYDRATES:		
APPLES, RAW	1 MEDIUM	75
APPLE PIE	1/6 MEDIUM PIE	400
APPLE SAUCE	1/2 CUP	95
APRICOTS, CANNED	3-4 AND 2 T. JUICE	75
APRICOTS, FRESH	2-3	55
APRICOTS, DRIED	4-6 HALVES	100
ASPARAGUS, RAW	8-12 STALKS 5"	25
ASPARAGUS, CREAMED	1/4 CUP	100
BANANAS, FRESH	1 MEDIUM	100
BEANS, STRING, FRESH	1 CUP	25
BEETS, SLICED, FRESH	1 CUP	65
BISCUITS, BAKING POWDER	1 MEDIUM	100
BLACKBERRIES, FRESH	1/2 CUP	40
BLANC MANGE, CHOCOLATE	1/2 CUP	220
BLANC MANGE, PLAIN	1/2 CUP	150
BREAD, WHOLE WHEAT	1 SLICE, 1/2"	55
BREAD, WHITE ENRICHED	1 SLICE, 1/2"	60
BREAD, WHITE, RAISIN	1 SLICE, 1/2"	65
CABBAGE, RAW	1 1/4 CUP	30
CAKE, ANGEL	PIECE 3" CIRCUMFERENCE	140
CAKE, CUP, PLAIN	1 MEDIUM	200
CAKE, PLAIN	PIECE 2" x 1"	110
CAKE, SPONGE, HOT WATER	PIECE 3" CIRCUMFERENCE	155
CANTALOUPE	1/2 MEDIUM	45
CARBONATED BEVERAGES	6 OUNCES	80
CARROTS, RAW	2, 4" LONG	40
CARROTS, STEAMED, CUBED	1/2 CUP	20

CAULIFLOWER, STEAMED	1 CUP	30
CAULIFLOWER, RAW	1 CUP	25
CELERY	3/4 CUP OR 4 STALKS	20
CHERRIES, SOUR, FRESH, STONED	1 CUP	65
CHERRIES, SWEET, FRESH, STONED	1 CUP	65
CHOCOLATE, BITTER	1 SQUARE	140
CHOCOLATE CREAM MINT	1	50
CHOCOLATE FUDGE	PIECE 1 1/2" x 1" x 3/4"	100
COCOA, POWDERED	1 T.	20
COCONUT, PREPARED	1/3 CUP	115
CORN, CANNED	1/3 CUP	60
CORN, GREEN	1 MEDIUM EAR	85
CORN SYRUP	1/2 CUP	470
CORNFLAKES	1 CUP	50
CORNMEAL, COOKED	2/3 CUP	80
CORNMEAL, RAW	1/4 CUP	130
CORNSTARCH	1 T.	35
CRACKERS, GRAHAM	1	35
CRACKERS, SODA	1	30
CRANBERRY JELLY	2 T.	100
CREAM PIES WITH MERINGUE	1/6 MEDIUM PIE	300
CUCUMBER, FRESH	1/2 CUP OR 1 SMALL	15
DATES, UNSTONED	3-4	85
DOUGHNUTS	1	170
FIGS, DRIED	2 LARGE	100
FLOUR, WHEAT, WHITE, ENRICHED	1 CUP	405
FLOUR, WHOLE WHEAT	1 CUP	400
FRUIT COCKTAIL	3/8 CUP	100
GRAPEFRUIT	1/2 LARGE	100
GRAPENUTS	1/3 CUP	100
GRAPES, CONCORD, DELAWARE	SMALL BUNCH	80
GRAPES, MALAGA, TOKAY	SMALL BUNCH	75
GRIDDLE CAKES	1 CAKE 4" DIAMETER	80
HOMINY GRITS, COOKED	1 CUP	25
HONEY, STRAINED	1 T.	15
LEMON JUICE	1/2 CUP	10
LEMONS	1 MEDIUM	25
LETTUCE	1/4 LARGE HEAD	20

MACARONI, COOKED	1/2 CUP	230
MAPLE SYRUP	1 T.	50
MINCE PIE	1/6 MEDIUM PIE	455
MUFFINS, PLAIN	1 MEDIUM	115
OATS, ROLLED, COOKED	2/3 CUP	100
ONIONS, RAW	1 SMALL OR 3 T.	10
ORANGE JUICE	1/2 CUP	55
ORANGES	1 MEDIUM	50
PARSNIPS, COOKED	1 MEDIUM OR 1 CUP	95
PEACHES, CANNED	1 HALVES, 3 T. JUICE	85
PEACHES, FRESH	1 MEDIUM	50
PEACHES, DRIED	4 MEDIUM HALVES	145
PEARS, CANNED	2 HALVES, 2 T. JUICE	80
PEARS, FRESH	1 MEDIUM	70
PEAS, CANNED	1/2 CUP	55
PEAS, DRIED, RAW	2 T.	85
PEAS, GREEN, SHELLED	3/4 CUP	75
PINEAPPLE, CANNED	1 SLICE, 3 T. JUICE OR 1 1/2 CUPS SHREDDED	90
PINEAPPLE, FRESH	1 CUP	74
POTATOES, SWEET, BAKED	1/2 MEDIUM	100
POTATOES, WHITE, RAW	1 MEDIUM	100
POTATOES, WHITE, CREAMED	1/2 CUP	150
PRUNES, DRIED	4 MEDIUM	75
PRUNES, STEWED	3 MEDIUM AND 2 T. JUICE	100
RAISINS, DRIED SEEDED	3/4 CUP	320
RASPBERRIES, FRESH	3/4 CUP	75
RHUBARB, FRESH	1 CUP	20
RICE, STEAMED	1 CUP	200
RICE PUDDING, CREAMY	1/2 CUP	110
ROLLS, YEAST	1 MEDIUM	120
SALAD, CHICKEN	1/2 CUP	235
SALAD, TOMATO, LETTUCE	1 SERVING	100
SAUCE, WHITE MEDIUM	1/4 CUP	110
SPINACH, COOKED	1/2 CUP	25
SQUASH, HUBBARD, COOKED	1/2 CUP	50
STRAWBERRIES, FRESH	3/4 CUP	40
SUGAR, BROWN	1 T.	50
SUGAR, GRANULATED	1 T.	50

SUGAR, POWDERED	1 T.	30
SUNDAE, VANILLA ICE CREAM WITH CHOCOLATE SAUCE	1/2 CUP	220
TAPIOCA, CREAM	1/2 CUP	190
TOMATO JUICE	1/2 CUP	25
TOMATOES, CANNED	1/2 CUP	25
TOMATOES, FRESH	1 MEDIUM	30
TURNIP GREENS, COOKED	1/2 CUP	20
TURNIPS, COOKED	1/2 CUP	20
WAFFLES	1, 6" DIAMETER	215
WATERMELON	PIECE 2 1/2" x 2" x 3"	85
WHEAT, SHREDDED	1 LARGE BISCUIT	100
YEAST, COMPRESSED	1 CAKE	25

FOODS CLASSED AS LARGELY PROTEIN:

ALMONDS, CHOCOLATE	5	105
ALMONDS, SALTED	10-12	95
BEANS, BAKED	1/2 CUP	100
BEANS, LIMA, COOKED	1/3 CUP	100
BEANS, NAVY, COOKED	1/2 CUP	105
BEEF, HAMBURG STEAK, BROILED	CAKE, 2 1/3" DIAMETER, 1/2" THICK	120
BEEF, ROUND, BROILED	PIECE 2 1/2" x 3" x 1/2"	125
BEEF, SIRLOIN STEAK, LEAN, BROILED	PIECE 4" x 3" x 3/4"	350
BUTTERMILK	1 CUP	85
CHEESE, AMERICAN	1" CUBE	115
CHEESE, COTTAGE	1/3 CUP	75
CHICKEN, LEAN MEAT, COOKED	3 SLICES 3 1/2" x 2 1/2" x 1/4"	115
CHOCOLATE BEVERAGE MADE WITH MILK	3/4 CUP	210
EGGS, SCRAMBLED	1/2 CUP	180
EGGS, WHOLE	1	75
FISH, LEAN, BROILED	PIECE 4" x 2 1/4" x 2/3"	125
GELATIN, GRANULATED	1 T.	35
HAM, BAKED	PIECE 4" x 2 1/2" x 3/4"	280
HAM, BOILED	1 OZ.	85
ICE CREAM, VANILLA	1/3 CUP	150
GELATIN DESSERT	1/3 CUP	75
JUNKET, PLAIN	1/2 CUP	115

Lamb chop, broiled	1	250
Lamb roast	slice 3 1/2" x 4 1/2" x 1/8"	200
Liver, raw	piece 4" x 3" x 5/8"	130
Milk, skimmed	1 cup	85
Milk, whole	1 cup	165
Oysters, raw	1/3 cup or 3 1/2 large	70
Pork chop, broiled	1 medium	250
Salmon, canned	1/2 cup	205
Soda water with vanilla ice cream	2/3 glass	200
Soup, cream of pea	1/2 cup	135
Soup, cream of tomato	1/2 cup	125
Walnuts, English	10 meats or 1 1/2 T. chopped	100
Foods classed as largely fat:		
Bacon, cooked	2 slices	100
Butter	1 T.	100
Cod liver oil	1 T.	100
Cottonseed oil	1 T.	125
Cream, 40%	1/2 cup	440
Cream, 18%	1/2 cup	245
French salad dressing	1/2 cup	470
Lard	1 T.	125
Mayonnaise dressing	1 T.	90
Oleomargarine, fortified	1 T.	110
Olives, green, unstoned	3-4	50
Olive oil	1 T.	135
Peanut butter	1 T.	90
Peanuts, shelled, roasted	9-10	50
Russian salad dressing	1 T.	100

Body Heat Rejection

Any part of the skin that is not covered by clothing or hair is called "exposed skin" because it is open to the surrounding environment. Exposed skin is sensitive to changes in temperature, radiant energy, and wind velocity. If the surrounding air is warmer than the skin, thermal energy will move from the air through the skin to the body core. Should this be allowed to continue, then ultimately the temperature of the deeper portions of the body will begin to rise. However, if the surrounding air is colder than the skin, then thermal energy will move from the body core through the skin and to the air. If this condition is permitted to continue, the body temperature will fall.

Four important factors affect the rise or fall of body temperature:

1. The difference between the temperature of the air and the temperature of the skin;
2. The rate of air movement;
3. The relative humidity of the air;
4. The difference between the temperature of the surface of the skin and the temperature of surrounding walls and other surfaces.

It is important to note, however, that the body possesses adaptive mechanisms which prevent large rises or falls in body temperature when the temperature of the environment changes. These adaptive mechanisms may be of a behavioral or a reflex nature, as indicated in Figures 1-13 and 1-14.

COMPENSATORY RESPONSES

	THERMAL SURROUNDINGS	HEAT PRODUCTION CHANGE
1	COLD AIR WINTER SEASON COLD CLIMATES	INCREASED PHYSICAL ACTIVITY INCREASED FOOD INTAKE DECREASED FLUID INTAKE AND SWEATING
2	HOT AIR SUMMER SEASON HOT CLIMATE	DECREASED PHYSICAL ACTIVITY DECREASED FOOD INTAKE INCREASED FLUID INTAKE AND SWEATING

COMPENSATION IS OVER A PERIOD OF TIME AND IS PARTLY VOLUNTARY.

Figure 1-13.

ADJUSTMENTS TO SKIN HEAT LOSS

	THERMAL SURROUNDINGS	SKIN-BLOOD FLOW CHARGE
1	COLD AIR LOW THERMOSTAT SETPOINT LOW SURFACE TEMPERATURES	BLANCHES SKIN, REDUCED BLOOD FLOW, LIMITED SWEATING, SHIVERING; INCREASED HEAT PRODUCTION
2	HOT AIR HIGH THERMOSTAT SETPOINT HIGH SURFACE TEMPERATURES	PINK SKIN, INCREASED BLOOD FLOW SWEAT RATE RAISES; INCREASED HEAT LOSS; AREA OF MOIST SKIN INCREASED

ADJUSTMENTS ARE RAPID AND CONTROLLED BY NERVOUS REFLEX.

Figure 1-14.

Clothing and Human Comfort

One important factor human beings can use in order to have some control over their comfort in relation to temperature, is in clothing worn. Clothing, of course, provides thermal insulation and also prevents hot or cold air from moving over the body. Just as there are units of measurement concerning the effectiveness of the insulation used in homes, certain units of measurements can be used to determine the thermal insulation value of clothing. This unit is called the "clo". The greater the "clo" value, the greater the thermal insulation quality of the garment.

Obviously, different types of fabrics and clothing have varying "clo" values. Winter clothing, for example, that is lined or fur-insulated usually has a "clo" value between 0.8 and 2.0 "clos". It is interesting to note that even the very best quality of arctic winter clothing can insulate no better than 25 times lightweight clothing. These values would range between 2.0 and 4.0 "clos". During recent years the average indoor clothing "clo" value of men's and women's garments has changed from an average of 0.9 "clo" units to those shown in the following table:

CLOTHING ENSEMBLE CLO VALUES

	AN AVERAGE OF 12 SEDENTARY INDOOR CLOTHING ENSEMBLES	LIGHT, SUMMER, SUB TROPICAL	HEAVY, WINTER, NORTHERN USA
Men	0.76	0.38	1.18
Women	0.74	0.27	1.20

(All values in clo units)

The "clo" values of induvidual garments range from 0.01 to 0.03 for pantihose and socks to 0.49 to 0.63 for a light jacket or a warm dress, as indicated in Figure 1-15, which appears in the following pages. By adopting different cold-weather and hot-weather styles of dress, people are able to vary the "clo" value of their clothing as well as the amount of exposed body surface.

By repeated exposure to the changing heat of summer or cold of winter, individuals become seasonally or residentially accustomed to the climate and temperature. The process is known as "acclimatization" or "adaptation". Usually, acclimatization requires several days or weeks. It should be obvious that the heat-acclimatized person in warm surroundings will feel more comfortable than the non-acclimatized individual. On the other hand, the cold acclimatized person will feel more comfortable in cold surroundings than the non-acclimatized person. Therefore, a consideration of acclimatization is just as important as the "clo" value of clothing, when one is concerned with the comfort of human beings. For example, two people with the same kind of clothing but with different acclimatization backgrounds may note different degrees of comfort even if they work at adjacent desks.

INDIVIDUAL GARMENTS: INSULATION IN CLO UNITS

INSULATION VALUE*	ITEM
0.01	PANTIHOSE
0.02	SANDALS
0.03	COOL SOCKS
0.04	SHOES GIRDLE
0.05	BRIEFS BRAS & PANTIES
0.06	UNDERSHIRT MINI-SKIRT
0.09	T-SHIRT SUMMER SHIRT
0.14	COOL L.S. KNIT SHIRT HALF SLIP
0.19	WOVEN S.S. SHIRT SUMMER BLOUSE
0.26	SUMMER TROUSERS
0.29	WOVEN L.S. SHIRT L.S. BLOUSE
0.32	WARM TROUSERS
0.37	L.S. WINTER SWEATER
0.49	WARM JACKET
0.63	WARM DRESS

* CLO VALUES ARE ADDED FOR EACH GARMENT WORN IN AN ENSEMBLE TO OBTAIN OVERALL CLOTHING INSULATION.

SOURCE: JOHN FLETCHER, ENVIRONMENT, ENERGY AND SOCIETY, 1973.

Figure 1-15.

Human Health and the Environment

Good health can be maintained during a wide range of environmental temperatures, provided proper clothing and an adequate diet are provided. However, an individual's health may be adversely affected by a sudden onset of cold weather or prolonged cold, wet periods, and heat waves. During such periods, excessive deaths usually result from a variety of respiratory diseases, such as influenza during times of cold, and heat stroke during unusually hot weather. If a great deal of time is spent indoors, it is important to maintain even temperature and to avoid extremely humid or dry conditions. Uneven temperatures and humid conditions can increase the likelihood of numerous bacterial and viral infections. On the other hand, dry conditions may contribute to coughing and certain allergic conditions. This is due to the drying of the mucous membranes of the nose and throat.

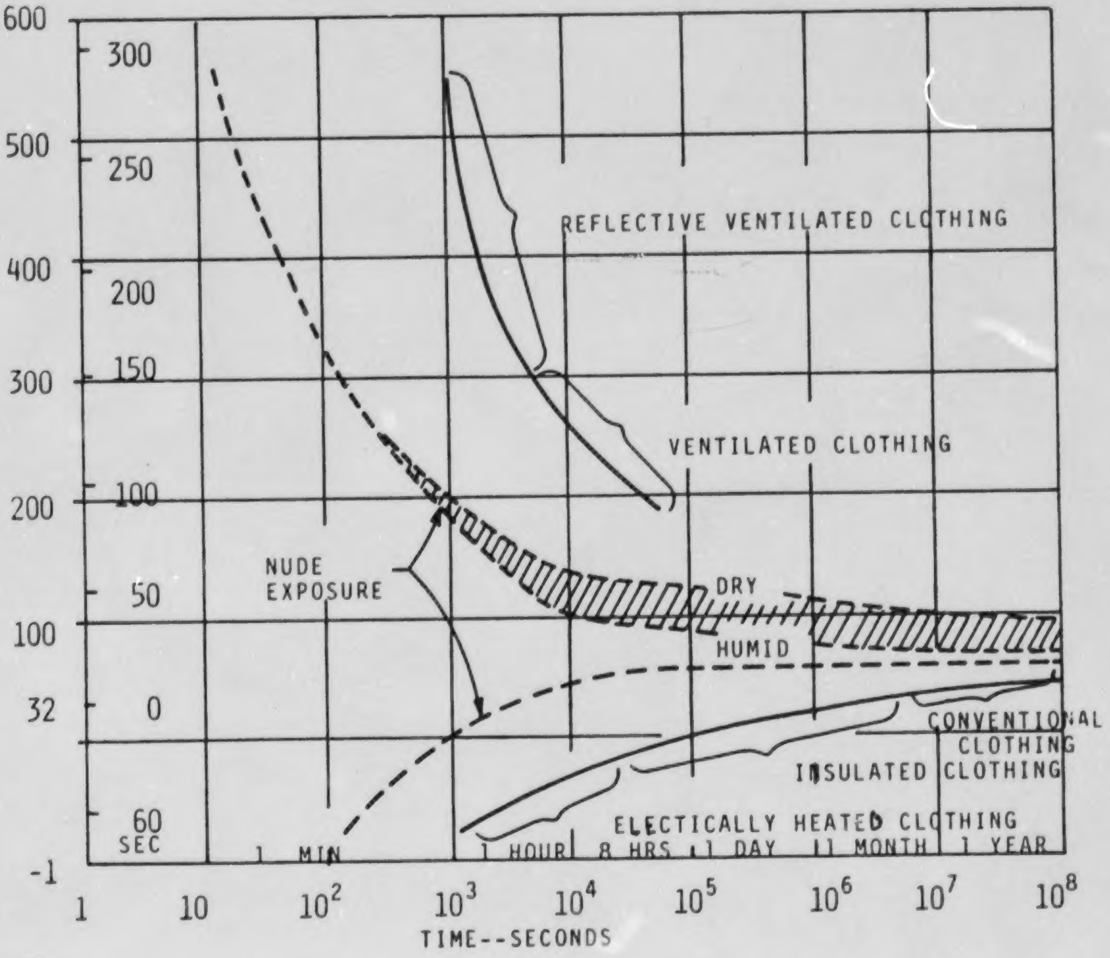
Temperature comfort is, of course, necessary if a worker is to achieve optimum production. Therefore, when worker efficiency is being considered, it is of the utmost importance to determine the usual temperature under which work is done. The time of day when individuals are at work is very important to consider. For example, 8-hour shift work is usually from 8 A. M. to 4 P. M., 4 P. M to 12 midnight, and 12 midnight to 8 A. M. In which of the three shift periods would the lowest temperature be expected? The midnight to 8 A. M. shift would be the coolest because these are the hours of darkness.

Just as temperature is important to worker productivity, it also is important to individuals confined to their homes. For example, babies, the ill, or the handicapped must remain in a relatively narrow temperature zone if they are to survive. This is why newborn babies are often placed in incubators. Also, this is why very old people are often very uncomfortable during certain times in a 24-hour period.

For short periods, human beings can withstand extreme temperatures. However, the more extreme the temperature, the shorter the duration of tolerance. Additionally, in very high or very low temperatures, the human body requires some kind of protection. For example, people working in such extreme environments as near a blast furnace or in a meat locker must have special clothing. Figure 1-16, on the following page, shows the relation between tolerance time and temperature. Note here that, with special protective clothing, a person can withstand a temperature of -40° F to +320° F for a period of one hour. Also note that, without clothing and under hot, humid conditions, an individual can only withstand temperatures between +40° F to +170° F, and +40° F to -130° F.

TEMPERATURE-TIME SURVIVAL CHART

THE MAN-MADE ENVIRONMENT-TEMPERATURES FOR HUMAN SURVIVAL IN AIR



SOURCE: JOHN FLETCHER, ENVIRONMENT, ENERGY AND SOCIETY, 1973.

Figure 1-16.

CONDITIONS THAT AFFECT HUMAN COMFORT

Although human comfort zones are measured in several different ways, all of them rely upon:

Dry Bulb Temperature (T_{DB})
Wet Bulb Temperature (T_{WB})
Velocity of Air Movement, or Wind Speed (V_{air})

Hot and Cold Air

When the air is still and at a fixed mid-humidity level, and the dry bulb temperature (T_{DB}) is higher than the skin temperature (T_{SK}), the air feels warm. However, if the T_{DB} is lower than the T_{SK}, the air feels cool. On the other hand, if the air is moving, the body feels cooler because heat is lost from your body by evaporation. Obviously, the sensation of cold is magnified with an increase of air movement.

Additionally, when the surface temperature (T_{surf}) of nearby windows, walls, floors, and ceilings are significantly higher or lower than a comfortable dry bulb temperature reading, one feels uncomfortable. Therefore, variations in comfort depend primarily upon the difference between the T_{DB} and the T_{surf}. However, it should not be forgotten that such variations in comfort also depend upon clothing, activity level, air movement, and humidity level.

Outdoors, T_{surf} is replaced by sky temperature, solar radiation, ground temperature, and wall temperature. An example of maximum and minimum temperatures is shown in Table 1-7, which appears on the following page. In studying this table, it should be noted that the average change in the T_{DB} necessary for staying in the comfort zone is much smaller in range than the monthly range of average outdoor temperatures. You should also note that the T_{SK} for comfort is somewhat narrow in range.

MAXIMUM AND MINIMUM TEMPERATURES

Mean Temperature*		Max. F	Min. F	Range F
TSK	(comfort)	95°	91°	4°
TDB	(comfort)	93°	72°	19°
TSK	(outdoors)	100°	75°	25°
TDB	(outdoors-Texas)	98°	20°	78°
TDB	(outdoors-Continental USA)	105	-3	108
T (surf)	(outdoors-** Texas)	139°	6°	133°
T (surf)	(outdoors-** Continental USA)	168°	NA	NA

---

*Individual reactions to temperature may vary substantially. The mean TSK is usually the average skin temperature for feet, lower and upper leg, trunk, arms, hands and head. However, the feet and leg temperatures are usually much more variable than the trunk and head TSK. Outdoor TDB are average monthly air temperatures for July and January (max.°F and min.°F, respectively). Mean T (surf) outdoors is the mean of shade and exposed ground temperatures and sky temperature and surface temperature of nearby objects.

** Estimated 1-hour averages on light surfaces. Computer models for dark surfaces predict occasional values as high as 198°F or one hour.

Table 1-7.

Air Movement

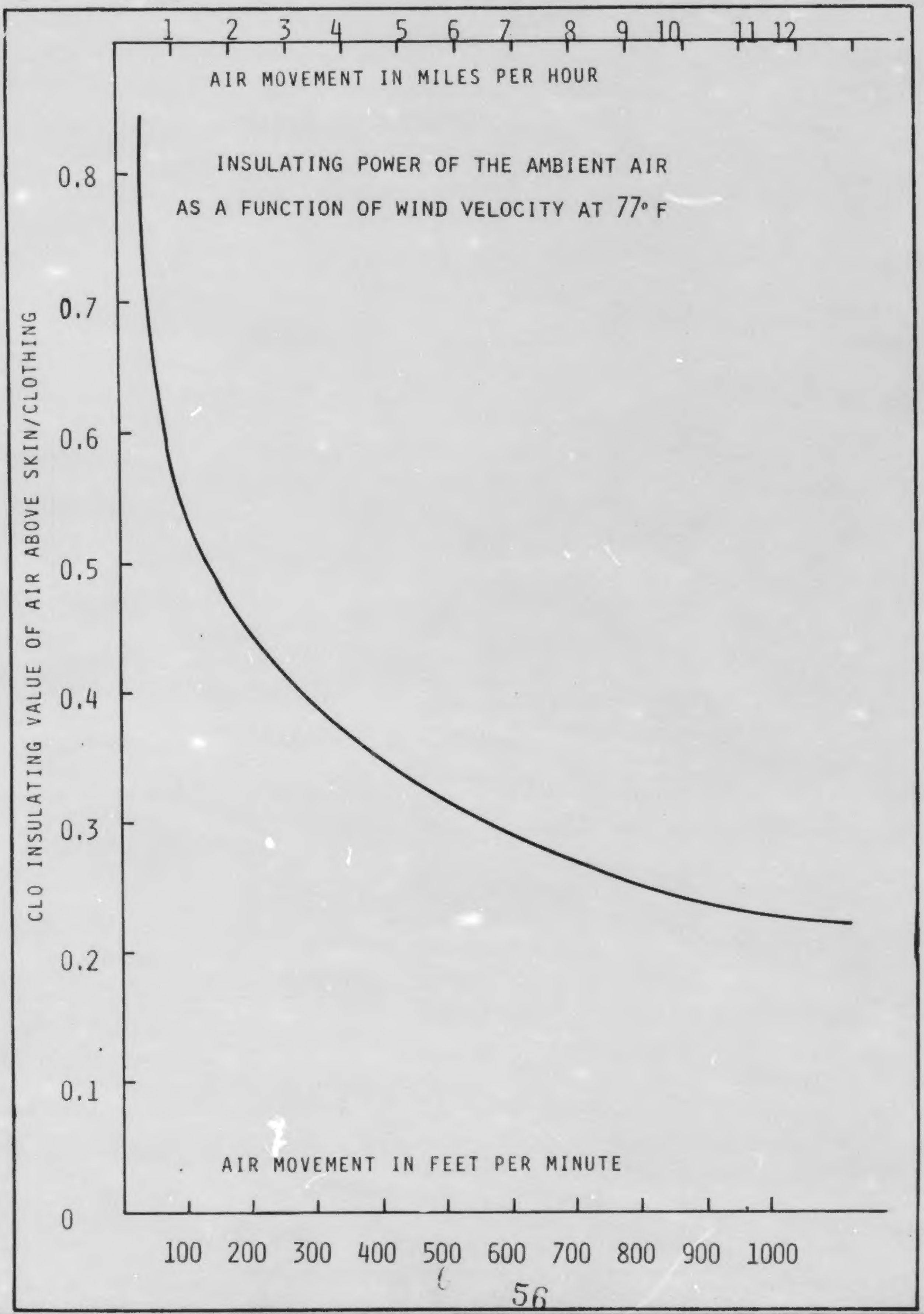
In warm indoor environments, our comfort is quite dependent upon air movement because:

1. it permits cooling by evaporation;
2. it removes the insulating layer of still air above the skin and clothing.

Moderate air movement (V_{air} = 200-400 feet per minute, or 2-1/4 to 4-1/2 mph) is very effective in helping to cool the body in surrounding temperatures of 77° F to 95° F. Air movements above 400 feet per minute tend to disturb dust and papers. However, when air is moving at 200 feet per minute, there is less convective cooling and an increased sense of warmth. This is probably desirable below 77° F but undesirable above 77° F.

Look at Figure 1-17 on the following page. This shows the effect of varying air movements upon the "clo" value of the insulating layer of air above the skin and clothing. Notice that as the velocity of the air increases, the "clo" value of the insulating air above one's skin decreases. This explains why ceiling fans and large pedestal fans help one feel more comfortable in warm surroundings.

Either indoors or outdoors when the temperature is between 65° F and 77° F, both T_{DB} and T_{WB} are important. Between these temperatures a relative humidity (RH) between 20% and 60% is preferred for comfort. When the RH is above 60% (at temperatures between 65° F and 77° F), the air begins to feel moist, and evaporative cooling is reduced. If the relative humidity is above 85%, the skin feels "sticky." Below 20% RH, the air feels dry and the skin tends to dry and even occasionally crack.


1
2
3
4
5
6
7
8
9
10
11
12
AIR MOVEMENT IN MILES PER HOUR
INSULATING POWER OF THE AMBIENT AIR
AS A FUNCTION OF WIND VELOCITY AT 77° F
CLO INSULATING VALUE OF AIR ABOVE SKIN/CLOTHING
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
AIR MOVEMENT IN FEET PER MINUTE
100
200
300
400
500
600
700
800
900
1000

CONTROLLING BUILDINGS FOR HUMAN COMFORT

The need to control the temperature, humidity, and air movement inside a building may vary. It may be for purposes of safety, odor removal, for the contents stored, or for human comfort. If the above factors are controlled comfort, there are two factors to be determined (figure 1-18):

1. the rate of occupancy (how many persons will be inside);
2. the duration of occupancy (whether people typically remain in the building for just a few minutes at a time, for a period of one hour, or for a period of four hours or longer).

Buildings such as sports arenas and churches are usually occupied by a large number of people for a short period of time. Additionally, such buildings may be occupied for only a few times each week.

In contrast, buildings such as schools or hospitals may be occupied by a large number of people for a long period of time during the greater part of each week. Therefore, different spaces have different thermal conditioning requirements according to occupancy and duration of stay. Because of this, the enclosed environment can be maintained at different comfort index values for comfort. For example, in a classroom that is occupied by 30 students for 90 minutes the temperature will rise because of body heat production. Therefore, the room must be both cooled and ventilated. In contrast, however, 30 people may pass through an entrance hall of the same size during a period of 90 minutes. However, because of the short period of occupancy, there will be no need to cool or ventilate it to classroom comfort conditions.

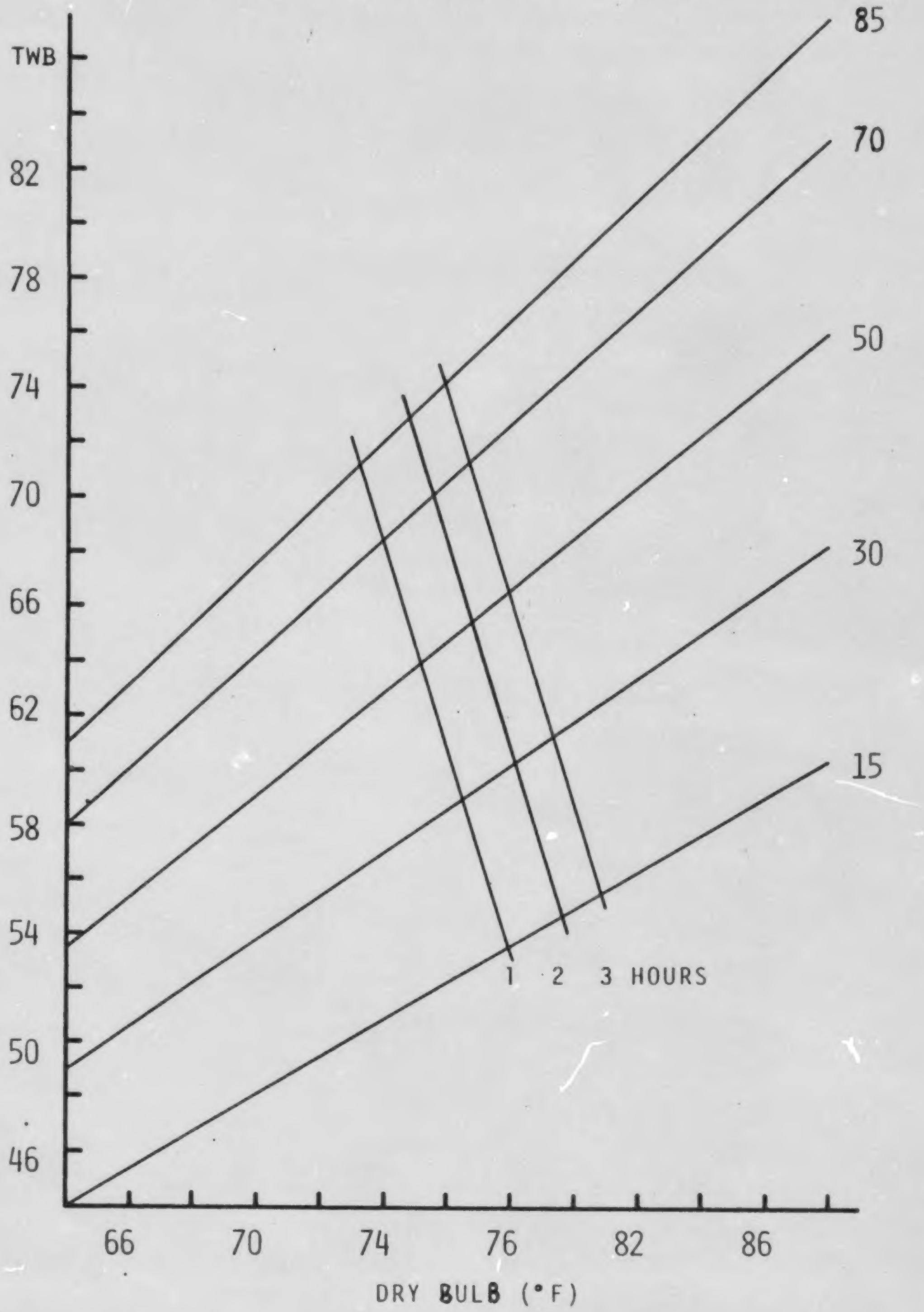
Preferred temperatures are usually measured for one-, two-, or three-hour periods by vote or by preferred thermostat settings. Average values are plotted as "comfort lines" on a graph of T_{DB} versus T_{WB}. Refer now to Figure 1-19, which is shown in the following pages.

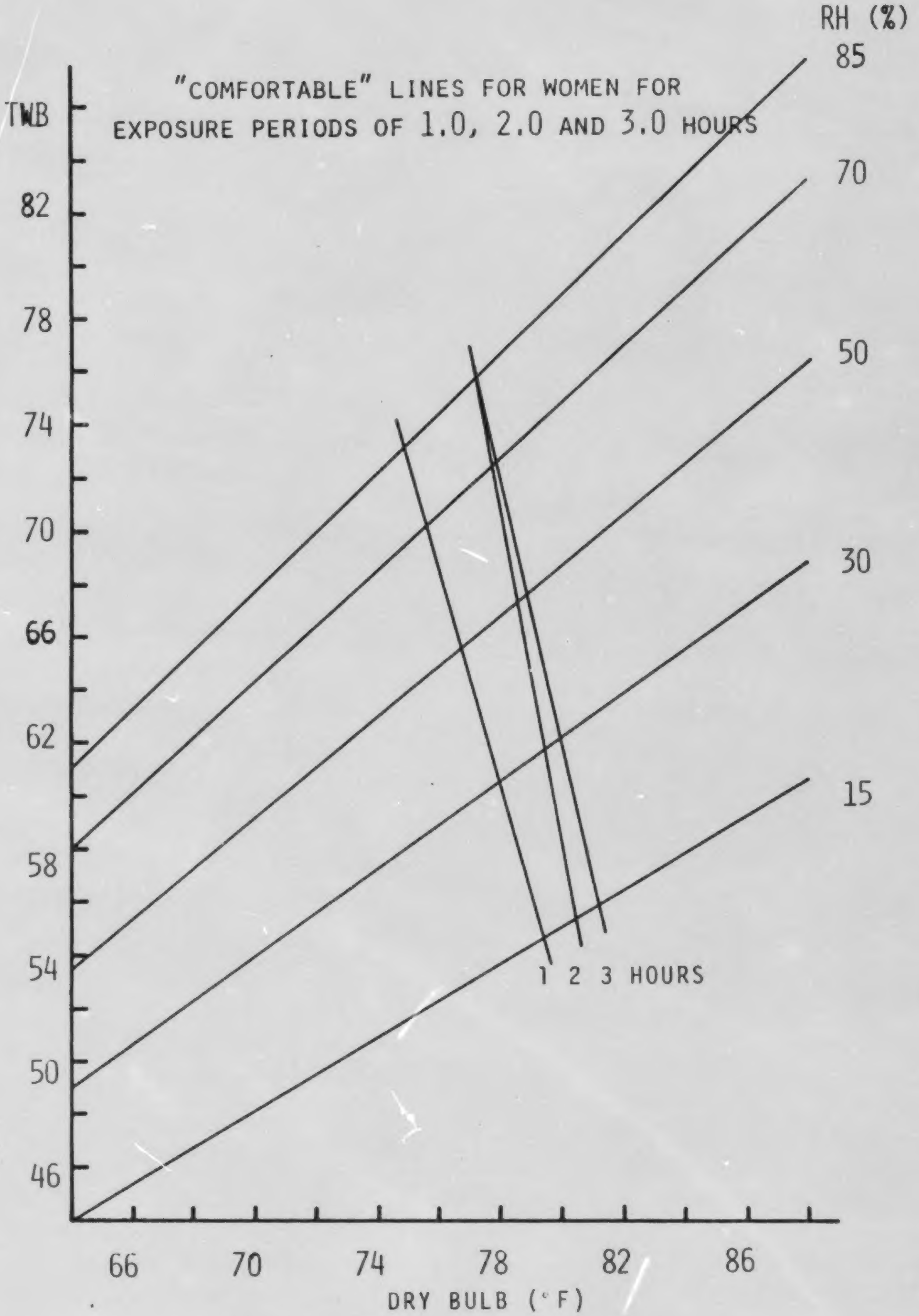
OCCUPANCY AND DURATION OF STAY IN BUILDING TYPES

SPACE OR BUILDING	OCCUPANCY	DURATION OF STAY PER PERSON
1. ENTRANCE LOBBIES	FEW AT A TIME	SHORT
2. ELEVATORS	ONE OR SEVERAL	SHORT
3. CONVENIENCE STORES	SEVERAL	MINUTES
4. RESTAURANTS	VARIABLE	1/2 - 1 HOUR
5. CLASSROOM	SUBSTANTIAL	3/4 - 1 1/2 HOURS
6. LIBRARIES	SEVERAL OR MANY	VARIABLE
7. CHURCHES	SUBSTANTIAL	1-2 HOURS
8. SPORTS ARENAS	THOUSANDS	2-3 HOURS
9. MOVIE THEATERS	HUNDREDS	2-4 HOURS
10. OFFICES	FEW	8 HOURS
11. MOTEL ROOM	ONE OR TWO	8 HOURS OR MORE
12. HOSPITAL ROOM	ONE OR TWO	24 HOURS OR MORE

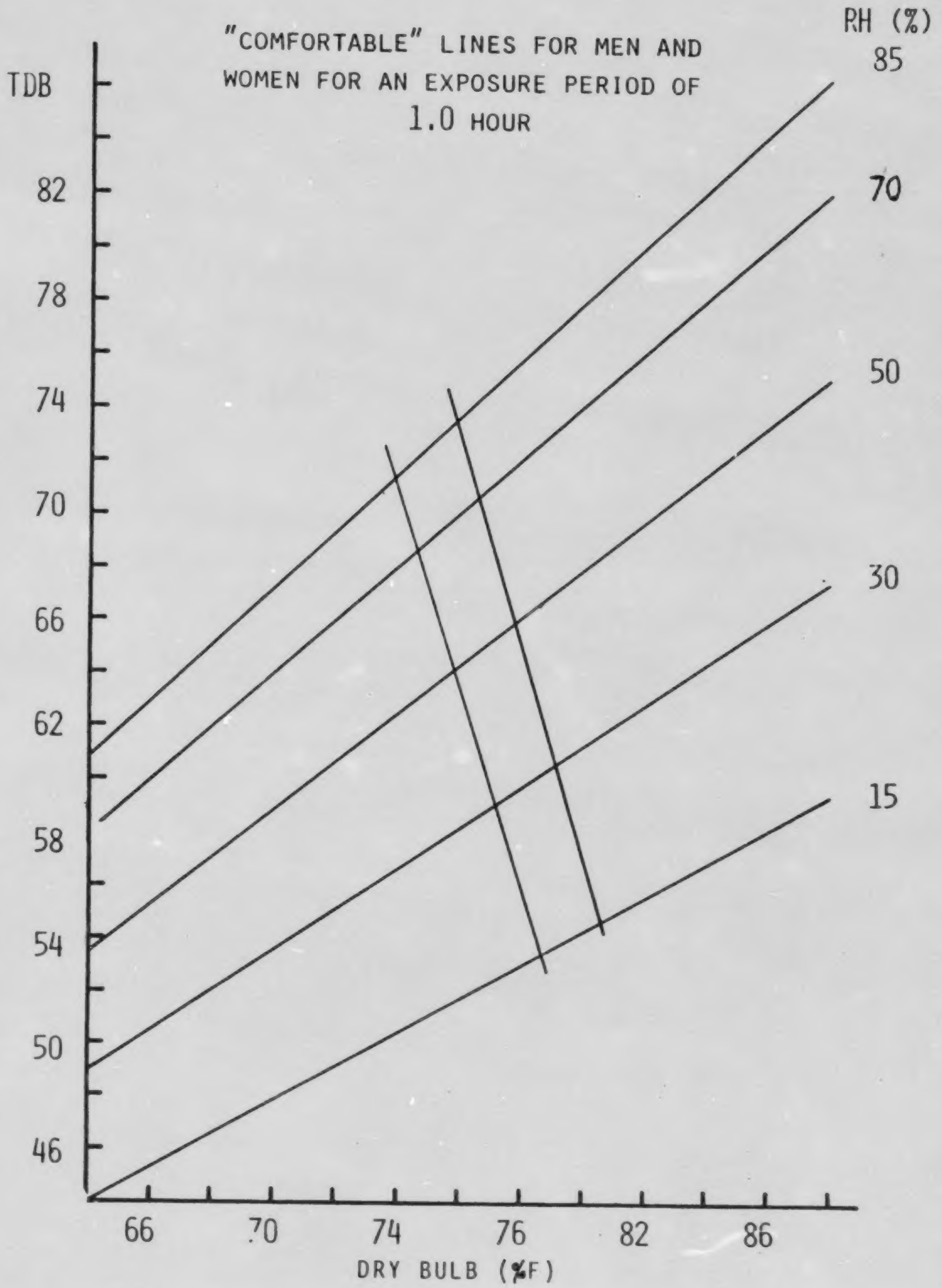
Figure 1-18.

"COMFORTABLE" LINES FOR MEN EXPOSURE PERIODS OF 1.0, 2.0, AND 3.0 HOURS





"COMFORTABLE" LINES FOR WOMEN FOR EXPOSURE PERIODS OF 1.0, 2.0 AND 3.0 HOURS



"COMFORTABLE" LINES FOR MEN AND WOMEN FOR AN EXPOSURE PERIOD OF 1.0 HOUR

Human Activity and Clothing

In order to understand the conditions under which the human body remains in continued thermal comfort, we should examine the heat balance equation below:

BODY HEAT PRODUCTION = BODY HEAT LOSS TO SURROUNDINGS

Body heat production is increased by such activities as physical work or eating. Body heat loss is decreased by raising the temperature, reducing air movement, or by increasing the "clo" insulation value of garments worn. If any or all of these factors are brought into play, the heat balance equation is shifted temporarily to:

BODY HEAT PRODUCTION - BODY HEAT LOSS TO SURROUNDINGS = **BODY HEAT STORAGE**

How does the body respond to heat storage? Initially, there is an increase in the breathing rate, a greater flow of blood to the skin and a feeling of warmth that may become uncomfortable. If body heat storage continues, the individual begins to breathe heavily, sweat, flush, and develop difficulty in paying attention.

This condition can, however, be reversed by -

1. reducing heat production
2. increasing convective cooling
3. increasing evaporative cooling
4. reducing thermal insulation

Heat production can be reduced by intermittent work, rest pauses, and/or slower work. Convective cooling, evaporative cooling and reduced thermal insulation can all be brought about by reducing the number of garments worn, by moving to a cooling area, or by fanning the air.

If people are exposed to prolonged periods of heat without compensation or treatment, the results will be dehydration, heat fatigue, loss of temperature, and finally death. Because of this, individuals who must suffer long periods of heat should be provided with chilled water for drinking, as well as for wetting their skin.

During the hot summer months, most people wear fewer layers of clothing that is light in color and made of thin fabrics. Additionally, during the summer, more of the skin area is exposed to allow for more evaporative cooling.

Those activities associated with the least heat production include sleeping, lying, reclining and sitting. During light work, however, heat production is more than doubled. During moderate activity, heat production may even be quadrupled. In athletes and people engaged in hard physical activities, heat production may be increased 10 to 20 times.

When considering body heat production, body size and sex are important factors. Even when performing the same task, tall, heavy people produce more heat than short, light individuals. Figure 1-20, which appears in the following pages, gives representative heat production rates for men and women in Btu/hour. These are individuals of typical North American stature and build.

When exercise ceases, heat production continues for various periods of time. However, it is not uncommon for heat production to continue for at least an hour after exercise has ceased.

How can heat balance be achieved during work? Obviously, heat loss must somehow be increased. This may be achieved by wearing fewer clothes or by reducing the T_{DB} and T_{WB} below resting confort levels.

Just how much adjustment is needed to achieve heat balance? This depends upon the level of body heat production and/or the environmental conditions. For example, at 75° F, 50% RH (relative humidity), and 30 r. p. m. air movements, refer to Figure 1-21, which appears in the following pages.

TABLE OF HEAT PRODUCTION RATES

	TYPICAL VALUES FOR BTU/HR
ASLEEP	
SLEEPING, MEN OVER 40	260
SLEEPING, MEN AGED 30-40	280
SLEEPING, MEN AGED 20-30	280
RESTING	
LYING MODERATELY RELAXED	320
LYING AWAKE--AFTER MEALS	340
SITTING AT REST	400
VERY LIGHT ACTIVITY--SEATED	
WRITING	430
TYPING	550
POLISHING	570
VERY LIGHT ACTIVITY--STANDING	
RELAXED	440
TYPING	460
POLISHING	480
LIGHT ACTIVITY--SEATED	
PLAYING MUSICAL INSTRUMENTS	690
REPAIRING BOOTS AND SHOES	720
AT LECTURE	730
LIGHT ACTIVITY--STANDING	
WASHING CLOTHES	610
IRONING	890
SCRUBBING	1040
LIGHT ACTIVITY--MOVING	
SLOW MOVEMENT ABOUT ROOM	600
VEHICLE REPAIR	820
WASHING	1000
MODERATE ACTIVITY--SITTING	
ROWING FOR PLEASURE	1190
CYCLING AT 8-11 MPH	1360
CYCLING RAPIDLY	1640

	TYPICAL VALUES FOR BTU/HR
MODERATE ACTIVITY--STANDING	
GARDENING	1380
CHOPPING WOOD SLOWLY	1480
SHOVELING SAND SLOWLY	1620
MODERATE ACTIVITY--MOVING	
GOLF	1290
TABLE TENNIS	1380
TENNIS	1500
HEAVY ACTIVITY--LYING	
LEG EXERCISES, AVERAGE	1790
SWIMMING BREAST STROKE AT 1.6 MPH	1950
SWIMMING BACKSTROKE AT 1.0 MPH	1980
HEAVY ACTIVITY--SITTING	
CYCLING RAPIDLY--OWN PACE	1980
CYCLING AT 10 MPH--HEAVY BICYCLE	2120
CYCLING IN RACE 100 MI IN 4 HR., 22 MIN.	2340
HEAVY ACTIVITY--STANDING	
CHOPPING WOOD RAPIDLY	1790
SHOVELING SAND RAPIDLY	1830
SAWING WOOD BY HAND	1900
HEAVY ACTIVITY--MOVING	
SKATING AT 9 MPH	1860
SKIING AT 8 MPH ON LEVEL	2140
CLIMBING STAIRS AT 116 STEPS PER MINUTE	2340
VERY HEAVY ACTIVITY--SITTING	
CYCLING AT 13.2 MPH	2380
GALLOPING ON HORSEBACK	2720
SCULLING 97 STROKES/MIN.	3000

	TYPICAL VALUES FOR BTU/HR
VERY HEAVY ACTIVITY--MOVING	
FENCING	2500
PLAYING BASKETBALL	2720
CLIMBING STAIRS	2860
EXTREME ACTIVITY	
WRESTLING	3100
MARCHING AT DOUBLE	3160
ENDURANCE MARCHING	3520

NOTE:

BTU/HR IS THE RATE OF HEAT PRODUCTION PER HOUR. THESE MEASUREMENTS ARE GIVEN FOR A PERSON 69 INCHES TALL AND 167 POUNDS IN ABSOLUTE UNITS.

SOURCE: JOHN FLETCHER, ENVIRONMENT, ENERGY AND SOCIETY, 1973.

HEAT LOSS.

TYPICAL ACTIVITY	EVAPORATIVE HEAT LOSS	CLO FOR HEAT BALANCE
Sleeping	53 BTU/hr.	0.6 Light Winter Clothing
Scrubbing	226 BTU/hr.	0.14 T-Shirt & Briefs, Bra & Shorts
Climbing Stairs	644 BTU/hr.	0.05 Briefs Only

Figure 1-21.

Notice that Figure 1-21 shows that the required "clo" value at rest is twelve times greater than the "clo" value required during heavy work, such as climbing stairs. Therefore, it should be obvious that careful attention should be given to the "clo" value of clothing during different types of work and other activities.

Rather than reducing the "clo" value during heavy work, would similar results be achieved by raising the air movement to 100 r. p. m. If so, why?

It is also important to realize that if the T_{DB} and T_{WB} are reduced excessively in over-cooled rooms or in the winter, the body responses are:

1. blanched skin and "goosebumps"
2. shivering
3. increased body heat production

These symptoms are then followed by:

1. increased need for food
2. T(skin) reduced below comfort level
3. T(body) reduction and body chills
4. colds and respiratory infections, such as pneumonia and influenza.

If the above conditions should continue for a long period, then excessive deaths will occur even among young adults and healthy outdoor workers. In freezing outdoor temperatures and windstorms, frostbite will occur unless heavy protective clothing ("clo" values, 2-4 units) is worn. In the Texas Panhandle, temperatures below 0° F and winter windstorms frequently cause severe body chilling during December and January. This is, or course, due in a large part to the wind-chill factor.

Workplaces Versus Homes

Workplaces are usually temperature-controlled for shift work as well as for the comfort of healthy workers between the ages of 16-65 years of age. Locations of heavy and light occupations are usually segregated and individually air-conditioned. Eight hours is the usual limit for the working day of shift. After that, occupancy changes. In each working area, temperature conditioning is usually adjusted to the clothing and activity levels of the workers. Because the workers in each area have similar comfort needs, it is not difficult to adjust heat balance to their satisfaction. However, special requirements can be met by zoning work places for special cooling, ventilation, screening or warming.

By contrast, homes are the 24-hour, 7-day residences of heterogenous individuals ranging from babies of a few weeks to retired individuals well past 70 years of age. Additionally, some of the inhabitants are active while others are sedentary. Some are healthy while others are ill. Because of such variations, it is not uncommon to find that each member of a family has a different comfort zone.

In addition to individual needs for different comfort zones, various rooms (because of the nature of their function or use) will require different temperature conditioning. For example, in bedrooms, where 8-hour sleeping periods of low heat production is the usual activity, the comfort zone is different from that of the garage, workshop, home laundry, kitchen or playroom.

In multifamily houses there is greater use of control temperature conditioning as well as humidity control. As a result, the indoor climate of these dwellings is usually more nearly uniform than in smaller houses.

In studying the temperature conditioning needs of a house, it is important to examine the night and day temperature fluctuations of various areas. This can best be accomplished using 24-hour or 7-day thermographs. The use of several thermographs in different parts of the same house will better show the cycling effect of cool/night and warm/day conditions. The effects are most marked in open areas. Additionally, seasonal changes are also seen to be very marked in such locations.

As one might suspect, substantial temperature cycles are commonly found in non-conditioned or poorly insulated homes. Such fluctuations present additional problems in areas of high utility rates because of added expenses.

There are two problems that remain to be examined. First, the temperature-control mechanisms of the body are poorly developed in young children, and sometimes are impaired in older people. It is not uncommon for both groups to be unable to operate thermostats or windows for their personal comfort. Because body chilling and overheating is more likely to occur in such individuals, attention and assistance must be given to both groups.

The second problem encountered is individual differences in size, body build, activity level, and mobility. This alone makes it difficult to achieve satisfactory home air conditioning.

Energy Conservation

Active controls such as thermostats are devices which activate heating, ventilating, or cooling systems at constant power and then cut off when the set temperature point has been achieved.

Passive controls such as switches are those operated at the option of users. If left in the minimum load or OFF position until needed, and if turned ON as soon as comfort levels are inadequate, such controls are energy-saving. Time controls, such as those which activate heating lamps and other devices for a limited period, are also energy-saving devices used in comfort conditioning. The available options for energy-saving include:

1. Retain comfort control settings and pay the increased prices according to variations in climate.

2. Adjust comfort control settings to operate at higher summer temperatures and lower winter temperatures within the broad range of the comfort zone.

3. Install time controls or passive controls in such a way that heating, ventilating and air conditioning equipment will run only when buildings are occupied.

4. Convert from high cost/low efficiency equipment to low cost/high efficiency HVAC equipment for ventilation, cooling, and heating.

5. Eliminate use of air conditioning for all months in which outside temperatures are within the comfort zone.

6. Adjust air conditioning (cooling and heating) to compensate for internal heat gains from the number of people, lighting, cooking, and related factors.

7. Increase air movement for evaporation and convective cooling by using ceiling fans, pedestal fans, and natural ventilation.

8. Adjust clothing insulation daily to conserve heat when cool, and increase heat loss when hot.

9. Introduce single-room, zone, or spot air conditioning or ventilating, in place of total air conditioning.

10. Maximize the benefit of natural seasonal acclimatization by adopting seasonal clothing styles/types and by repeated daily open-air exposure.

11. Utilize existing architectural and construction features which will maximize the utility of natural ventilation, shade, and evaporative cooling in summer, and solar heating in winter, and reduce unwanted cold-night/hot-day cycling.

12. Develop future architectural and construction features which will maximize the utility of natural ventilation, shade and evaporative cooling in summer and solar heating in winter, and reduce unwanted cold-night/hot-day cycling.

Many options exist for improving thermal comfort passively and by changed behavioral patterns. Human comfort is affected by many variables, both energy-using and energy-conserving. Tradeoffs exist between the acceptance of hour-to-hour, day-to-day, and season-to-season changes in temperature within the comfort zone, and the use of energy to control temperature to these narrow limits. Energy conservation and cost savings in buildings are achieved by greater attention to variable levels of tradeoffs, with natural climate and human adaptability as important variable components.

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ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

BUILDINGS AND ENERGY CONSERVATION

STUDENT MATERIAL

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

BUILDINGS AND ENERGY CONSERVATION

ENERGY DEMAND FOR BUILDINGS

Building Crisis: When we speak of an energy crisis, we must also speak of an architectural crisis. The two are interwoven. The buildings in which we live and work consume well over a third of all the energy used in the United States, and building those buildings consumes over 15% of all the energy used in manufacturing. Even our use of transportation, especially the dependence on the private automobile, is affected by the way our communities, neighborhoods, and suburbs are planned.

To understand the seriousness of our situation, we must have some base for comparison. Twenty-five years ago, when we were beginning to fill our housing and other building needs, we were satisfying our national requirements with one-sixth of the amount of electrical energy we now use and less than half of today's total energy expenditure. Since then, our population has increased by about 45%, while our use of electrical energy has increased by 600% and our total consumption by 250%. If there had been a dramatic improvement in the quality of life proportionate to the per-capita increase in energy use, and if the perspective for the future was for an endless extension of that improvement - assuming endless reserves - there would be no reason to characterize our present condition as a crisis. However, if we discover that we are only doing things differently and that a good part of our effort merely corrects or offsets the damaging byproducts of these processes, then we are truly in a crisis of the gravest sort. It is not unlike a drug addiction that requires higher and higher dosages to offset the bad effects of the previous ones, combining with the constantly increasing difficulty of giving up the habit.

Since World War II, our method of building has changed noticeably, as have the materials of building. The mechanical systems have changed drastically, both in response to new formulations of comfort standards and in order to make the buildings built with the new materials and methods tolerable. The one constant, predictable tendency is that the energy use per square foot of building will be greater each year. We now find ourselves faced with the startling fact that our buildings alone consume about twice the electricity that was used twenty-five years ago for all purposes.

In addition to the impact on fuel shortages, this current manner of building results in an unacceptable level of pollution. Moreover, we are faced with imminent shortages in materials ranging from copper to the very plastics that were supposed to replace the natural materials. The dependence on technology to develop new sources for all our needs - power, materials, and control systems - has been overoptimistic at best and catastrophic at worst.

The list of warning signals can be extended almost indefinitely and each item has its own revealing ramifications. To understand the perspective, however, they must all be looked at together for they all stem from the same set of interconnected factors. Any attempt to solve only one of the trouble spots by shifting to an alternative method is bound to fail sooner or later. All problem areas are tied to the unrestrained growth projections that have, until recently, been largely unchallenged. We have become accustomed to the idea that we can do anything; that our resources can last forever; that it is simpler to discard something than to keep it in operating order, and that it is even desirable to throw it away as a stimulus to the economy; that appearance and aesthetics apply to the surface of a product rather than to the basic purpose served by the product and the means of producing it.

When we find that the presupposed growth is not possible and would be destructive, even if it were possible, we must then dismantle the ideology that justifies the conclusions and establish a set of attitudes and expectations that respond to the necessities of the real world. These attitudes generate forms, buildings, and communities that have their own beauty and maintain a close relationship to the great historical building traditions. What sounds apocalyptic turns out to be embarrassingly simple. The means are at hand, the opportunites are part of our everyday vocabularies. There is no need to wait for technical miracles or exotic discoveries. What is required is a willingness to identify the essentials of our culture and separate them - and ourselves - from the unnecessary and unproductive trappings.

These conclusions result through the growing realization that our modern buildings do not respond to the functional requirements that we claim are the underlying generators of form. In most commercial buildings it is difficult to be comfortable in offices that face south and west. It is impossible to introduce outside air into a room on a balmy spring day. Glass areas that originally related to views are now often vestigial sysbols with curtains drawn to re-establish privacy. Because of the dependence on mechanical systems, office buildings have larger and larger interior areas. At the same time, the perimeter spaces are considered more desirable and are reserved for the offices of high executives. The materials and finishes as well as the room sizes and ceiling heights of all residential buildings are constantly being down-graded and reduced. We know that the sun strikes each facade of a building at different hours and different angles, changing daily, but we do not build the facades differently. We know how trees can serve as windbreaks and selective sunshields, but they seldom are called upon to serve these purposes. We know something of the dynamics of air movement, and yet our buildings permit windswept terraces and gales through open colonnades. The design elements we work wity are too often the visible solutions to previous problems, now used symbolically and divorced from the reasoning that originally produced them.

The result has been a loss of tautness, comprehensibility, and clarity in our built environment. Even those remnants of our heritage that still remind us of the earlier traditions of reasonable and reasoned buildings are under constant threat of demolition. A return to a design attitude in which each decision is based on performing necessary work through the use of the most precise and careful means may bring us back to the enjoyment of the spare and lithe.

It is a beguiling prospect. Can it work? Are the savings great enough to warrant the reorientation? If we can achieve these savings, will they have any noticeable impace on our troubled world? Let us look at the facts.

Taking every aspect into account, buildings are responsible for over 40% of the energy used in the United States. The greater part of this usage is predetermined by architectural decisions. Energy is consumed in the complete process of making and assembling buildings' components, to operate the various systems during the useful life of buildings, in the transportation systems predetermined by decisions on how buildings are grouped together, and to demolish buildings or to dismantle the shells of buildings that have been destroyed in other ways.

Materials Processing and Transport

The Building Industry: The building industry is a large industry. In 1970, out of a trillion-dollar Gross National Product, buildings - excluding roads, bridges, and similar constructions - were responsible for $100 billion. Moreover, it is characteristic of buildings that they are high materials users in relation to the dollar value of their products. For example, $1 million worth of building may have three million pounds of material in it, while $1 million worth of automobiles may have only 800,000 pounds of materials, and $1 million worth of desk-top calculators may have only 30,000 pounds of materials. Buildings, then, are responsible for an even greater materials usage then their share of the Gross National Product would indicate.

The understanding of how this vast amount of material is used is important for a number of reasons. Materials are major users of energy in their extraction, refining, processing, adaptation for usage, transportation, and installation. Different materials that are suitable for interchangeable usages often have sharply divergent energy requirements in their manufacture. Availability of materials, components of materials, and feedstock for materials is rapidly becoming as critical as availability of energy. Misuse and overuse of materials to perform specific functions are as unacceptable aesthetically as they are economically. In order to come to grips with this problem, we must understand its true extent, the technical and social causes for its present form, the organizational instrumentalities that impede or assist changes in the way things are done, and the consequences of several available courses of action.

Material Elements: Studies that divide the nation's entire use into subcategories variously attribute about 35% to a little over 40% to industry. These divergencies may reflect inclusion or exclusion of certain items such as feedstock, transportation of industrial products, electrical use in the industrial process, or incorrect reporting of that were included in the data. The inability to learn the true status of production capacity and available crude oil in the petroleum industry during the period of intense shortages to consumers in 1973-74 is not an untypical result of the assembly and analysis of industrial statistics. Nevertheless, in the absence of more systematically gathered and circulated figures, 40% is a reasonable, broad assumption to work with. As a hypothesis, if we assume that the 10% of the Gross

National Product (GNP) represented by the construction industry uses about 20% of the energy used by all industry - a reasonable assumption in consideration of its large material utilization - the manufacture and installation of building components is responsible for about 8% of all energy for all purposes. In 1970, this represented about 5.75 million billion Btu of energy, or, in other terms, the equivalent of 38 billion gallons of oil, or the entire year's output of 385 thousand-megawatt electric generator plants. It has become common to ignore this characteristic of energy use through the construction of buildings, since the energy required to operate and maintain them is about four times greater. Nevertheless, changed patterns of building that would reduce the building energy commitment per square foot by 20% would save us the equivalent of 77 spare thousand-megawatt generating plants. (Not all of the industrial energy use is electrical. The work capability of a thousand-megawatt electrical plant is used here as a unit that is easier to visualize than 20 trillion Btu.)

There are two available mothods for reducing the energy that goes into the making of buildings: first, in the reduction in the amount of material, and second, in the selection of the material requiring the least energy to perform a certain function. For proper decisions, a detailed framework of all the energy uses in materials, products, and complete assemblies is required.

Energy Analysis: Economic input/output matrices are necessary to consider the importance of the material elements in building construction and conservation. These matrices are frameworks for orgainzing the economic information about the transactions that take place in the U. S. economy in a given year. The matrix identifies all sectors of the economy and lists them by title in vertical columns and in horizontal rows. Reading in one direction, a chart will show all purchases made by one industrial sector from all others, and, in the other, all sales by that sector to all others. The total in either direction represents the contribution of that sector to the gross national product, and all of these sectors together add up to the gross national product. Such matrices are in use by the government's Bureau of Economic Analysis of the Department of Commerce. It is important to recognize that it takes some time to gather and assess the data so that information is not current, but serves a useful purpose in identifying use patterns and trends.

Since among the purchases noted above for each industrial sector are the amounts paid for oil, gas, coal, and electricity, it is possible to translate the costs into gallons of oil, cubic feet of gas, tons of coal, and kilowatt-hours of electricity, and then convert these to Btu. Furthermore, it is possible to consider only that portion that relates to construction, determining how it is divided amoung some different building types - single-family residences, commercial buildings, and farm buildings, for example; how much energy each unit of a material - a ton of structural steel, for example - represents in place and where, in the various steps of manufacture that energy is applied; which basic industries are most important in establishing energy use, and what substitutions can be made without changing the end performance of the assemblies.

One study of this type indicates, for example, in 1967, 6.25% of all energy use was in building construction, and of this figure, almost 25% was in building maintenance and repair. Another 4.61% was in nonbuilding construction. Thus, the entire construction required 10.86% of our national energy budget, in addition to the energy needed to operate buildings. As an average, buildings require about 1,142,000 Btu per square foot to build, with substantial variations above and below this figure according to building type. More detailed information extracted from this study is given in the following example.

Energy Analysis Example: The example is based on a study, Energy in Building Construction, financed by a grant from the U. S. Energy Research and Development Administration, and was done jointly by Richard G. Stein and Associates and the Center for Advanced Computation at the University of Illinois.

The project determined definitively the amount of energy embodied in the end products of 18 new building categories, 14 new nonbuilding categories, 4 building maintenance and repair categories, and 13 nonbuilding maintenence and repair categories - a total of 49 categories, based on 1967 information from the Bureau of Economic Analysis, Department of Commerce, Dodge Reports, and other sources.

Over-all totals in these groupings are:

	Trillion Btu	% of total U. S. energy use in 1967
New building construction	3,421.6	5.15
Building maintenance & repair	733.5	1.10
Total building	4,155.1	6.25
New nonbuilding construction	2,499.9	3.76
Nonbuilding maintenance & repair	580.6	0.85
Total nonbuilding		4.61
Total construction	7,235.6	10.86

In the new building categories, one-family residences are the largest energy-using category, accounting for 781.0 trillion Btu, 18.8 percent of the new building use, although on a square-foot basis, it represents 39% of the total. Industrial buildings are next, using 11% of the energy, with 10% of the total square footage. Educational facilities use 10.5% of the energy, with 7.5% of the floor area. Office buildings use another 6% of the energy in their construction, and, as a category, account for about 6% of all building. While there are no total square footages noted for residential alterations and additions as a category, they use another 6% of the building energy. It can be seen that energy per square foot of building varies extensively from building type to building type. Table 2-1 compares area, total square footage, and Btu per square foot for the 18 new building categories.

The average use per building type varies extensively, from 625,000 Btu per square foot for residences to over 2 million Btu per square foot for laboratories. The over-all average is 1,142,600 Btu per square foot. About five years' worth of energy use goes into the building of the average one-family residence, and almost ten years' worth of operating energy is required for the construction of an office building.

The way energy is used in the building process varies considerably from sector to sector. The diagrams shown in Figure 2-1 indicate the percentages of energy embodied through different materials, and the amount of energy,

TABLE 2-1: 1967 ENERGY EMBODIMENT PER SQUARE FOOT OF BUILDING

	Square feet (x 1,000)	% of total	Trillion Btu	% of total	Btu/sq. Ft
Residential: 1-family	1,050,517	39.1	780.96	25.4	702,210
Residential: 2-4 family	40,609	1.5	34.83	1.1	625,140
Residential: garden apt.	352,452	13.1	147.75	4.8	736,200
Residential: high-rise			117.96	3.8	
Residential: alts. and addns.			261.85	(8.5)	
Hotel, motel	35,633	1.3	69.05	2.2	1,128,390
Dormitories	42,372	1.6	57.82	1.9	1,430,430
Industrial buildings	269,650	10.0	463.37	15.1	972,250
Office buildings	158,318	5.9	258.66	8.4	1,641,440
Warehouses	95,390	3.5	57.88	1.9	558,400
Garages, service stations	37,720	1.4	32.24	1.0	771,310
Stores, restaurants	170,146	6.3	197.01	6.4	941,130
Religious buildings	41,379	1.5	68.61	2.2	1,257,490
Educational	204,258	7.6	437.35	14.2	1,386,330
Hospital buildings	65,820	2.4	117.21	3.8	1,722,170
Other Nonfarm	123,698	4.6	231.07	7.5	
Amusement, social, rec.	(42,249)				1,379,700
Misc. nonresidential	(43,299)				1,102,230
Laboratories	(20,387)				2,073,750
Libraries, museums	(17,763)				1,744,550
Farm residences	not given		30.22	(1.0)	
Farm service	not given		57.88	(1.9)	

identified as "Direct energy," that is used on the construction site. For example, in one-family residences, direct energy, wood, and stone and clay products account for over 50% of all energy used. In high-rise residence buildings the three largest categories are direct energy, stone and clay products, and fabricated metals, accounting for about 65%. Where one-family residences use about 12% for direct energy (12.22% of 712,210 Btu equals 85,780 Btu per square foot, high-rise residence buildings require 20.31% (20.31% of 736,200 equals 149,400 Btu per square foot).

Finally, the study examined the everage energy embodiment per unit of material in order to permit the study of alternate assemblies that satisfy standards and performance criteria with different energy embodiments. The units used are those associated with the product being examined - board feet for lumber, square feet for glass, cubic yards for concrete, and a single brick for brickwork, as examples. The energy is not only the process energy at the point of manufacture, but all the energy required to mine or extract the raw material, to transport it, to refine it, to fabricate it, and to incorporate it in the building, including the prorated part of the energy required by the administrative activities related to that product.

Some of the values derived are:

	Unit	Btu per unit
Framing lumber (rough)	Bd. ft.	7,611
Glass, double-strength sheet	Sq. ft.	15,430
Ready-mix concrete	Cu. yd.	2,594,338
Paint (oil and alkyd)	Gal.	488,528
Asphalt roofing shingles	Sq. ft	25,334
Steel: hot rolled structural shapes	Lb.	18,730
Aluminum: rolled structural shapes	Lb.	92,146
Insulation (4.5" thick)	Sq. ft.	6,860
Common brick	1 brick	14,291

The information was tested by making several comparisons to determine energy embodiment in interchangeable assemblies:

Fireproof floor construction for high-rise buildings	(Btu per sq. ft.)
Steel with concrete fireproofing:	293,187
Reinforced concrete slab:	251,206
Composite construction:	172,021
Wood-frame building exterior walls with .07 U-factor	**(Btu per sq. ft.)**
Stud wall, wood shingles (including interior finish, insulation, etc.):	32,286
Stud wall, brick veneer (including interior finish, insulation, etc.)	171,033

According to our computations, if one evaluates the difference between electing to build the floor slabs in reinforced concrete rather than structural steel in one year's office buildings, the savings in oil would amount to three-million barrels. If wood wall finishers were used in place of the brick now used in one-family houses for a year, 5.07 million barrels of oil would be saved. There are obviously other important factors that affect these decisions - special performance requirements, availability, costs, maintenance, etc. Nevertheless, the comparisons indicate that a careful study of the materials of building will provide the opportunity for substantial reductions in the energy needed per square foot of building.

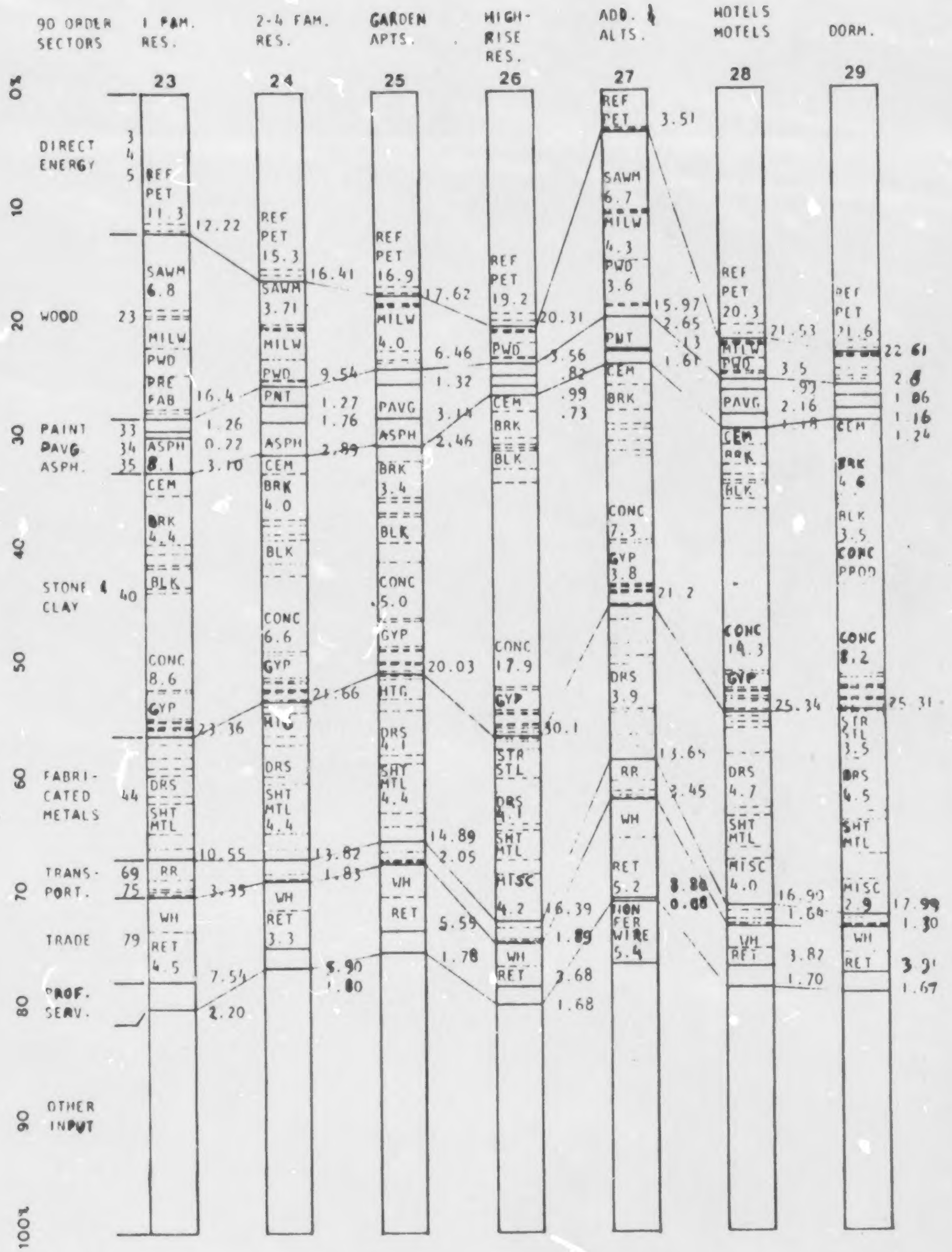

90 ORDER SECTORS
1 FAM. RES.
2-4 FAM. RES.
GARDEN APTS.
HIGH-RISE RES.
ADD. & ALTS.
HOTELS MOTELS
DORM.
23
24
25
26
27
28
29
0%
10
20
30
40
50
60
70
80
90
100%
DIRECT ENERGY
3
4
5
WOOD 23
PAINT 33
PAVG 34
ASPH. 35
STONE & CLAY 40
FABRICATED METALS 44
TRANS-PORT. 69
75
TRADE 79
PROF. SERV.
OTHER INPUT
REF PET 11.3
12.22
SAWM 6.8
MILW
PWD
PRE FAB
16.4
ASPH 8.1
1.26
0.22
3.10
CEM
BRK 4.4
BLK
CONC 8.6
GYP
23.36
DRS
SHT MTL
10.55
RR
3.35
WH
RET 4.5
7.54
2.20
REF PET 15.3
16.41
SAWM 3.71
MILW
PWD
PNT
9.54
1.27
1.76
ASPH
CEM
2.89
BRK 4.0
BLK
CONC 6.6
GYP
21.66
HTG
DRS
SHT MTL 4.4
13.82
1.83
WH
RET 3.3
5.90
1.80
REF PET 16.9
17.62
MILW 4.0
6.46
1.32
PAVG
3.14
ASPH
2.46
BRK 3.4
BLK
CONC 5.0
GYP
20.03
HTG
DRS 4.1
SHT MTL 4.4
14.89
2.05
WH
RET
5.55
1.78
REF PET 19.2
20.31
PWD
3.56
.82
.99
.73
CEM
BRK
BLK
CONC 17.9
GYP
30.1
STR STL
DRS 4.1
SHT MTL
MISC 4.2
16.39
1.89
WH
RET
3.68
1.68
REF PET
3.51
SAWM 6.7
MILW 4.3
PWD 3.6
15.97
2.65
.13
1.61
PNT
CEM
BRK
CONC 7.3
GYP 3.8
21.2
DRS 3.9
13.65
3.45
RR
WH
RET 5.2
8.86
0.08
NON FER WIRE 5.4
REF PET 20.3
21.53
MILW
PWD
3.5
.99
2.16
1.19
PAVG
CEM
BRK
BLK
CONC 14.3
GYP
25.34
DRS 4.7
SHT MTL
MISC 4.0
16.90
1.64
WH
RET
3.82
1.70
REF PET 21.6
22.61
2.8
1.06
1.16
1.24
CEM
BRK 4.6
BLK 3.5
CONC PROD
CONC 8.2
25.31
STR STL 3.5
DRS 4.5
SHT MTL
MISC 2.9
17.99
1.30
WH
RET
3.91
1.67

Figure 2-1

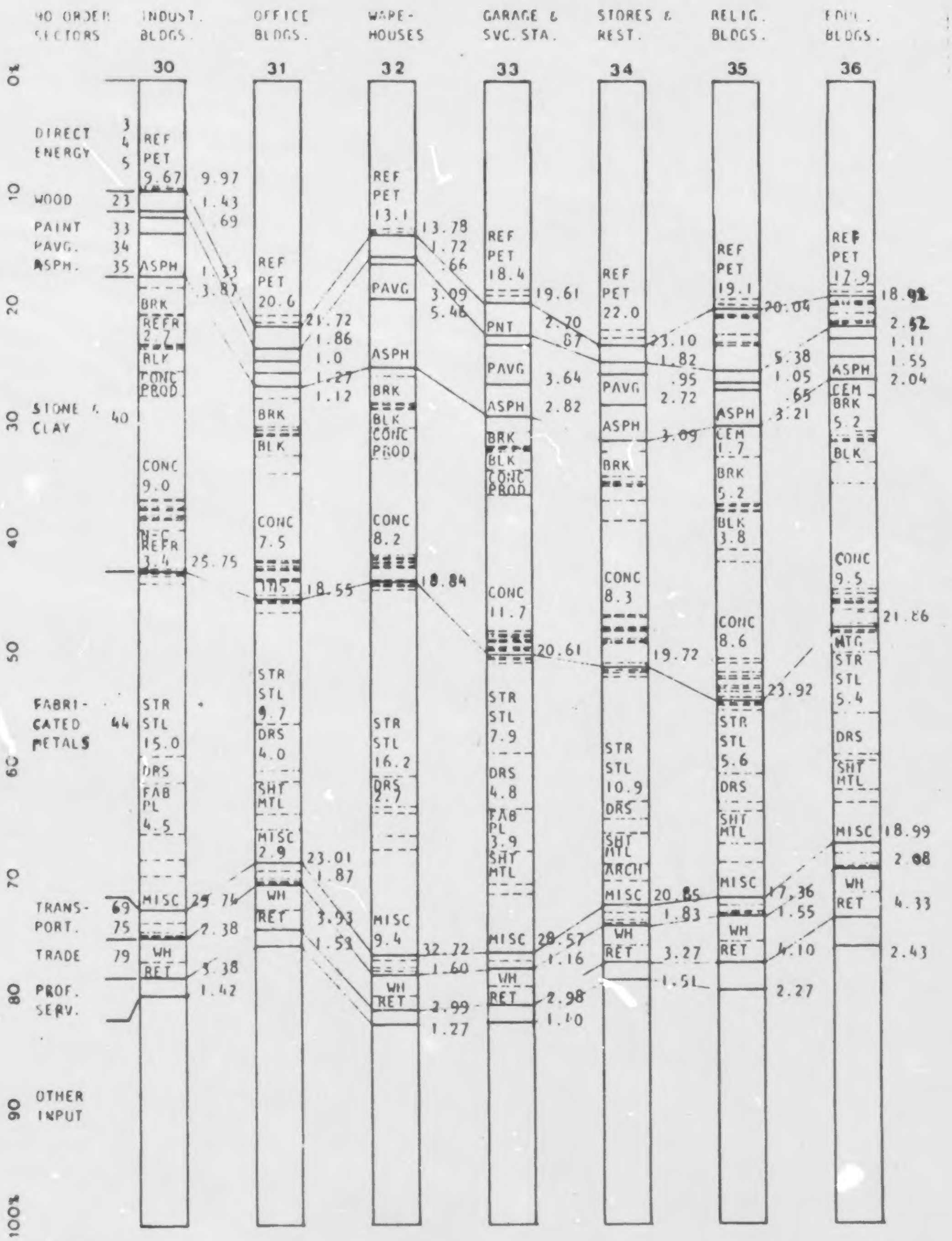


Figure 2-1 (continued)

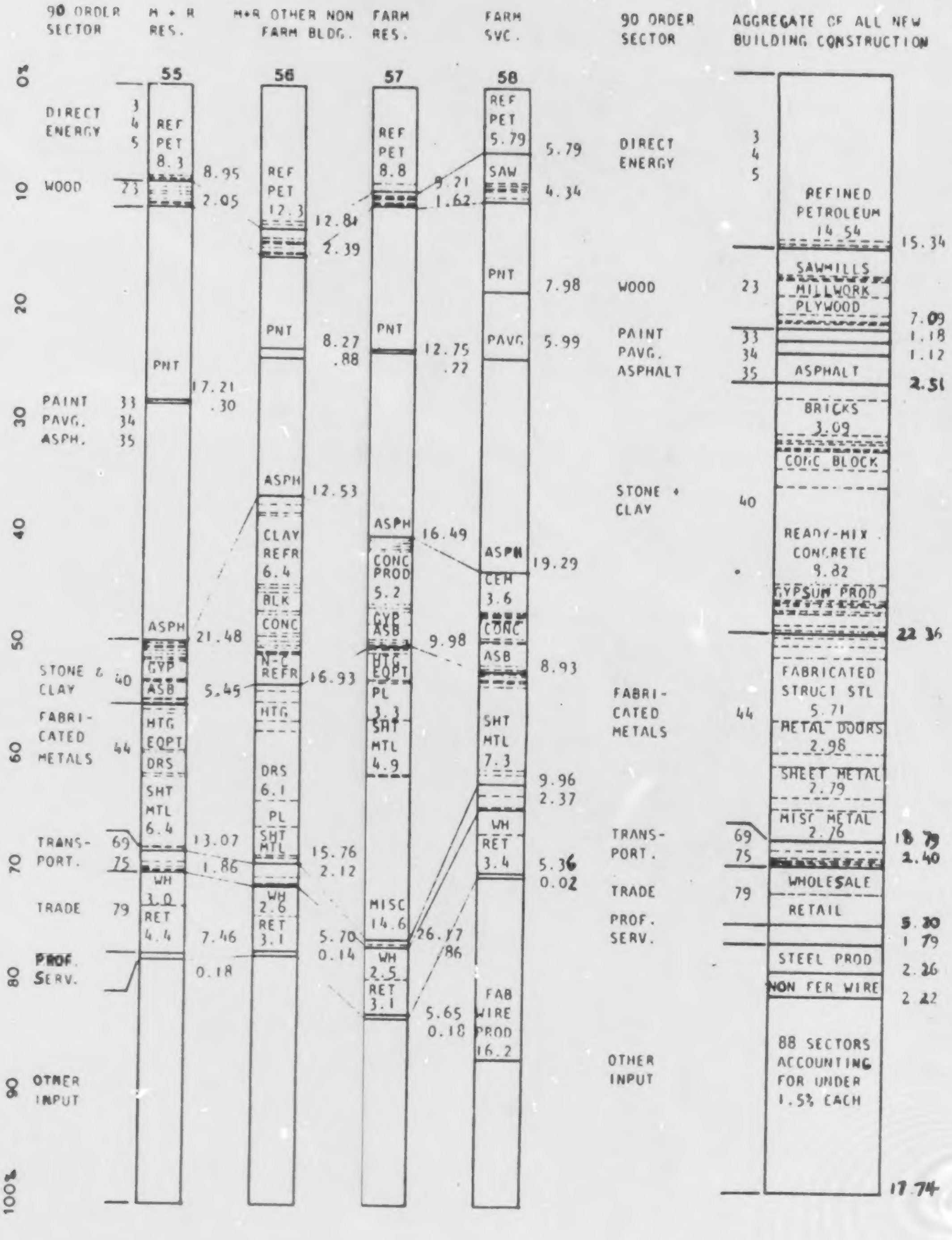


Figure 2-1 (continued)

Energy Use Per Pound: Tied into the studies of economic input/output matrices are a number of limited scope analyses establishing energy use per pound (or other unit) of a number of materials. Most of these figures have been attacked by the industries whose products appear to be the most energy intensive. A case in point is the aluminum industry's questioning the statistic that aluminum is five times as energy intensive per pound as steel. It naturally goes back to what process and what ore one used for the comparison, and what the end product is.

The different amounts of energy are required to refine different qualities of ore even to produce the same metal has been established by technical surveys. Figures for aluminum indicate the great difference in refining different qualities of bauxite - 63,892 Kwh per ton for the best 50% bauxite, between 72,844 Kwh and 86,327 Kwh per ton for lower grades of ore. Comparable studies use a figure of4,727 Kwh per ton for iron production. These figures are given in equivalent coal energy and assume an electrical generation and transmission efficiency of 29.8%. As a further comparison, there has been a great and worthwhile national effort to recycle cans, papers, and bottles. Certainly the energy save is appreciable. The total annual energy used in making beer and solf drink containers is 0.34% of the nation's total energy expenditure. The major metal that goes into the building industry consumes around 1.5%, almost five times as much. Since we are entering a period in which we are refining minerals that were by-passed years ago as being too low-grade to be of interest commercially, we can expect higher and higher refining costs, as well as greater and greater environmental problems in disposing of the tailings and waste products of the refining process.

Building Construction

Overuse of Materials: There is no doubt that our structures contain more material than stability and safety require. Almost every structural component is manufactured in a uniform linear manner - steel beams, timber, Lally columns, prestressed concrete beams, roof planking, steel decking - yet all these are subject to varying stresses throughout their lentghs. Concrete is crudely placed to eliminate the complexity of formwork and steel placement that responds to varying loads. Not understanding the structural contribution of materials that are incorporated into a structure for other than structural reasons could reduce the materials' use further - concrete fireproofing on steel, floor fills, continuous hung lintels, steel stairs, wood finish floors, lath and plaster membranes. The work of engineers, based on building failure studies, offers interesting grounds for reinvestigating computational methods. More rigorous structural analysis, leading to revised theory and codes, together with components that respond in their cross sections to varying structural demands, will allow substantial energy savings.

The design methodology used to compute amounts of steel, concrete, and other structural materials in buildings is inexact. The most characteristic piece of steel that goes into a building, the steel beam, is used inefficiently. A steel beam has a sophisticated cross section. Even within the dimensional limitations required by rolling-mill practice, the cross section works reasonably well. Nevertheless, in the designer's office, a specific beam is selected to satisfy the greatest loading condition of a span - the maximum bending moment, for example. At all other points of the span, it is excessive. The result is a vast overuse of steel. In contrast, we can look to those structures where weight is a critical element, or where the scale is great enough to warrant more structurally responsive forms. The boom or mobile crane, the structural steel on a ship, a bridge structure, and an airplane or high-performance car are all good examples of such forms. Open-web steel joints suggest that the kind of "vocabulary" that could result in material and energy savings.

Let us consider a simple concrete beam computation as an example of the overuse of materials. In figuring the loading carried by the structure, liveloads (that is, loads other than the weight of the structure) are assumed to be simultaneously applied over all rooms, corridors, lobbies and stairs. A 750-square-foot classroom for thirty pupils is computed to withstand a load of 40 pounds (sometimes 60 pounds) on every square foot, or a total of 30,000 pounds in addition to the weight of the structure. Thirty large children and a teacher might weigh 5,000 pounds. Adding another 1,500 pounds for friends, books, paraphernalia, and miscellany, would bring it to 6,500 pounds. Thirty-one desks and chairs might add another 3,000 pounds. The total would be 9,500 pounds - less than one-third of the figure produced by the computation. In addition, the values given for the concrete have a 300% safety factor, and for steel, a 50% factor, and the structural designer will select available steel for reinforcement and over-all dimensions for his beam cross section at the first size above that required by the computation, adding another 5%. In mixing concrete, the concrete plant will provide concrete above the design figure in order to avoid its rejection at the job, and this is frequently 10 to 20% above the value specified. On top of this, concrete continues to gain strength for years after it has been assumed to reach full design strength. No structural credit is taken, either, for such things as applied cement finishes or the capability of the structure to resist loads in a much more complicated and unified manner than is encompassed in the original calculation.

Rather than identifying the vulnerable points, the points of building failure, the engineers use contingency factors that are applied over the entire computational spectrum, so that every part has equal structural redundancy, increasing the weight appreciably and thereby somewhat reducing the safety factor achieved. The study of concrete building failures suggest that if high safety factors are maintained for each vulnerable point as connections and joints, and if care is taken to maintain bracing until the structure achieves adequate strentgh, the broad application of safety factors can well be reexamined.

It is quite obvious that reducing safety factors would permit concrete to be designed safely with less than half the material now used. Any structural engineer will confirm this, with two provisos: first, that building codes be rewritten; and second, that there be enough in the budget to pay for the labor that is necessary to build formwork, place steel, and mix and place the concrete carefully.

In addition to the saving in the individual members, there is a further cumulative saving. Since the weight of the building itself is substantially reduced, the size of the footings and foundations can be made smaller with further savings in material, reflecting both the more realistic structural analysis and the reduced loadings that the foundations and footing are designed to support. We have computed that in cement production alone this could result in energy savings of about 20 billion Kwh a year. Thus, this savings alone would provide the electric power for 4 million families, using a generous electricity usage budget per-family in the range of 5,000 Kwh per year.

Wood, too, is used excessively in frame buildings. For years, every member has been designed as though it were disconnected from the rest of the structure. Where concrete is at least deemed to operate as a T-beam, a floor joist is assumed to be unaffected by the subfloor and floor attached to it or the ceiling membrane below it. First steps are now being taken by the plywood manufacturers to see that structural credit can be granted for the assembled structure. Although such savings in this part of the building's energy curve are small in comparison with the energy savings possible in the operation phase, they are of consequence in themselves.

The extensive use of plastics and synthetics in place of natural materials has also increased energy use. Most plastics are produced by processes that use large inputs of energy, usually as heat, in their manufactore. The molecular structure of the petrochemical is broken down and rearranged to satisfy new purposes. The basic structure of the original material being supplanted by the synthetic resulted from the direct input of solar energy through photosynthesis. There has been a marked shift away from natural materials and toward synthetics. For example, twenty years ago the major resilient floor choices were linoleum, a linseed oil product, and asphalt tile, primarily an asphalt product. Today, vinyl and vinyl asbestos are the predominantly available replacements. Many metal components are replaced with polyvinylchlorides, and a certain amount of glass, a silicate product, has been replaced with acrylics and polycarbonates. Natural rubber has been replaced by neoprene; cotton cloth or wool used for shades, wall coverings, and carpeting has been supplanted by vinyls, acrylics, and polyesters; and linseed oil caulking and glazing compounds have been replaced with polysulfides and silicones. Not all these substitutions are undesirable; where they have a significantly higher performance capability or a longer life expectancy, their initially greater energy input may well be justified. Many, however, have some inherent problems that make it obvious they have been oversold and overused because of their greater profitability to the producer. In general, they do not age as gracefully as the natural products; they tend to break down suddenly under extended ultraviolet light or sheer passage of time; their disposal becomes a problem, since they are for the most part nonbiodegradable; and their performance in fires has been unexpected and, in some instances, disastrous. It is ironic that as primary objects in our throwaway culture, the plastic gadgets are the least disposable. A more disinterested investigation of the proper and improper uses of synthetics will undoubtedly result in a material savings in energy use.

Electrical Use in Building Construction: An analysis of electrical use in building construction employs economic input/output matrices similar to the following. Table 2-2 is prepared to organize the information into a number of categories that can be handled in the analysis. Some of the categories may be rather broad. For example, heating, plumbing, and structural materials may be in a single grouping, primary iron and steel in another, stone and clay products lumped in a third, and so on. The dollar value of each of these broad classifications that is consumed in the construction process can be ascertained. And in these categories, the amount of the total expenditure for electricity and other fuels is listed. An example of such a matrix for a 1970 analysis period is shown in Figure A of the table.

TABLE 2-2:
TABULATION OF THE ELECTRICITY USED IN BUILDING CONSTRUCTION IN 1970.

ELECTRICAL USE in BUILDING CONSTRUCTION A	Total sales of this item in GNP (million $) B	Total cost/$1000 of this item for all elec. energy C	Cost/$1000 of this item for elec. energy, appl. direct D	Total cost. All elec energy This item (million $) E	Cost. Elec. energy appl. direct. This item (million $) F	Cost. Elec. energy applied indirectly (million $) G	Rate. Elec. energy this industry (¢/Kwhr) H	Average rate. Elec energy. All industry (¢/Kwhr) I	Elec. energy directly used (million Kwhr) J	Elec. energy indirectly used (million Kwhr) K	TOTAL Elec energy (million Kwhr) L
22 Elec Lighting & Wiring	1786	17.60	4.61	31.5	8.25	23.25	1.05	0.875	790	2660	3450
36 Heating, Plumb'g, Struc'l	9557.6	21.10	4.33	201.0	46.2	154.8	0.78	0.875	5920	17600	23520
40 Other Fabricated Metal	1524.4	20.7	6.39	31.6	9.72	21.88	1.43	0.875	680	2500	3180
41 Primary Copper Mfr	2007.6	28.9	6.55	58.2	13.13	44.9	0.74	0.875	1780	5130	6910
42 Primary Alum Mfr	78.2	61.4	30.63	4.8	2.4	2.4	0.32	0.875	720	280	1000
47 Primary Iron & Steel	2950.6	28.0	13.90	82.5	41.0	41.5	0.78	0.875	5250	4750	10000
47 Stone & Clay Products	8785.3	27.20	14.82	239.00	130.0	109.0	1.04	0.875	12500	12500	25000
56 Lumber & Wood	5872.0	16.0	6.63	94.0	39.0	55.0	1.23	0.875	3160	6290	9450
74 Petroleum	1303.9	16.3	5.38	21.3	7.02	14.28	0.74	0.875	950	1630	2580
75 Electric Utilities	214.6	107.3	56.02	23.0	12.0	11.0	0.87	0.875	1380	1250	2640
76 Gas Utilities	42.0	9.6	.94	40	04	0.36	0.12	0.875	30	40	70
82 Motor Freight	1719.7	8.5	3.37	14.6	5.79	8.61	0.875	0.875	660	1010	1670
91 Wholesale & Retail	8530.2	17.1	12.34	145.0	105.0	40.0	0.875	0.875	12000	4570	16570
94 Business Services	4050.1	15.5	7.83	62.8	31.6	31.2	0.875	0.875	3620	3570	7190

113,230
million Kwhr

SOURCES
A Sci. Am Input Output chart
B ibid (Construction categories, excl hwy)
C Ibid
D Ibid
E B×C
F B×D
G E−F
H 1967 Census of Mfr. Dept of Comm
I Ibid
J F×H
K G<I
L J&K

NOTE This represents electric energy use in 88.5% of the Construction Industry's share of the GNP (excluding highways) 49.3% represents materials 39.8% represents value added. Extrapolating for 100% produces a figure of 128,000 million Kwhr. Total U.S. produc. of elec. energy in 1969 (per EEI) was 1,556,996 million Kwhrs

Since all reporting was done in dollars, it was necessary to assign different costs paid by different industries for the same product as reported by the United States Department of Commerce in order to translate the dollar values into quantities. These vary significantly. As an example, in 1967, primary aluminum manufacture paid 0.32 cents per Kwh; primary iron and steel, 0.78; and other fabricated metals (excluding heating, plumbing, and structural) paid 1.43 cents per Kwh. Such figures permit a broad computation of electrical energy used directly and indirectly in the gross groupings. They do not begin to tell the difference in energy use within a category - between extruded aluminum and sheet aluminum, for example, or between plywood and particle board.

Extrapolating the results of items that represent 85% of the industry to the full 100% produced a figure of 128 billion Kwh of electricity used by the building industry in 1970. Since the entire amount attributed to "Large Industrial and Commercial" users in 1970 was 480 billion Kwh, 20% of total industrial use of energy going into the building construction sector appears to be reasonable.

Building Equipment

Space Conditioning: Once a building is completed and its useful life begins, its consumption of energy, lasting fifty years or more, is uninterrupted until it is abandoned or demolished. The devices that actually consume the energy are the mechanical systems that have been incorporated in the building. We tend to forget, though, that the only purpose for having these systems in the first place is to allow the building to be used effectively for its intended purpose, whether this is health care, family living, education, or the sale of pots and pans. At the risk of oversimplification, it is worth describing a building as a generic object.

A building is an enclosed space erected for some predetermined purpose. Its primary reason for being is that its purpose can be better performed if it is not subject to the vagaries, unpredictability, or unsuitability of the climate around it. Where and when the outside climate is compatible with the intended purpose, no enclosure is required and the activity takes place in the open air. Such activities are familiar to all of us - outdoor markets, sports areans, theaters, restaurants. When some part of the activity requires a separation from the elements, a membrane is placed between the activity and the outdoors. This may be an animal skin enclosure, a masonry wall and thatched room, a snow-block dome, or a piece of cloth, depending on its purpose, its location, and the means available to the people creating the separation. Once this new enclosed volume has been created, the conditions within it can be modified. A fire can create heat for body comfort, cooking and light. Adjustable vents in the skin of the structure can selectively allow or prevent the passage of outside air. Water can be collected and carried into the house either by the bucket, by capturing rain, or by pumping. And waste can be removed from within the enclosure. Fundamentally, these are the criteria and the major mechanical requirements of a building. The special purposes served and the sophistication of the demands, solutions, and control systems all have major roles in differentiating a colonial house in Salem, Massachusetts, from the John Hancock Building in Boston.

Mechanical Systems: The prevalent term for mechanical systems in buildings is "environmental control technology". The provision of centrally produced environmental modifications was a preoccupation of the Romans - direct descendants of words for their systems persist in our current English terminology, such as "furnace", "duct", and "aqueduct" - but the industrialization of these components has been recent and has, in fact, permitted the intensive development of our new cities. The Romans, in building such structures as the Baths of Caracalla or the Baths of Diocletian, provided separate spaces in the structure for furnaces and for heating water, and passages in the walls and floors for the hot air and water to be conducted to the spaces using them.

It was not until the late eighteenth and early nineteenth centuries that people began to expect mechanical systems in their buildings. At first, these were added as visible systems in the previously unequipped spaces, and only in the last hundred years have they been buried in walls or placed between the structure and the applied interior finish. Today, as more and more space is required for proliferating systems, we find a topological development in buildings, in which the usable rooms are not defined by the structure of the building, but are boxes free of the walls and floor slabs allowing a continuous hollow space around them for the network of pipes and ducts. In some complex buildings the mechanical systems are located in interstitial spaces, as they have been termed. These are complete floors that alternate with the floors for human occupancy and are linked by large vertical shafts. Housing the mechanical plant in these buildings requires that more than 50% of the building's floor space be assigned for this purpose.

In the analyzing of building demands on energy systems, the most common practice has been to analyze each energy-consuming activity and find ways to lessen the demands of the building and improve the performance of the equipment. Both the teaching of this material and the application of the knowledge in the design of buildings is based on a series of formulas and computational methods that produce numbers, quantities, and sizes. The resulting energy use is far in excess of what is actually required to provide the comfort conditions that are sought. The equipment analysis, however, has been especially fruitful, since it can be isolated and examined. While this approach tends to perpetuate some of the attitudes that produce the crisis of direction our buildings now face, the improved knowledge of system performance is most useful.

The crisis referred to is the fragmentation of building decisions - the consideration of mechanical systems as something separage from the basic building design. In re-establishing a unified approach to building design, it is obviously essential to incorporate all that has been learned about improving the planet. Engineers and architects now talk of total energy systems for buildings. The underlying idea of total energy is so fundamental, so sound, that it is incredible to think of it as a new concept. Design based on the interrelationship between various energy uses only needs the next expansion - the inclusion of the natural (nonmechanical) energy exchanges to be a true total energy system.

Ventilation: The ventilating systems are considered an independent function and are separated from the other mechanical systems for purposes of calculation and design. Their design must be integrated into the heating and cooling requirements, since it would be unacceptable to dump large volumes of zero degree air into a space, even if the radiators in a room could cope with this amount of cold air. The ventilating air will therefore be tempered, thus contributing to the over-all heating of the space. Whether the amount of air introduced has been reasonably determined is another matter entirely.

Illumination: Lighting is an energy use in the building that requires an examination in greater detail and only a reference of a highlighting nature is presented here. In the conversion of electricity to light, part of the energy becomes visible light, part becomes heat directly. Eventually the light also becomes heat. The efficiency of the light source in converting electrical energy to light refers to the percentage that goes into light as opposed to that which goes directly into heat. Fluorescent lights are about two to three times as efficient as incandescent in converting electrical energy to light. However, they are still only 20% efficient; that is, 20% of the electrical energy goes into light, and 80% into heat. Whenever any light is turned on, it is contributing some heat to the space whether this heat is desired or not. If the space has a thermostat controlling its heating or cooling input, that heat will be taken into account either by requiring less heat from another source (possibly an oil-or gas-fired heating system) or by requiring more cooling to offset the heat if it is not wanted. Within this description, every building with electric, candle, or gas lighting has a heat-of-light system, a heating system that takes advantage of the heat contributed by lights. Some electric utility companies and some engineers have encouraged the use of heating systems, with heat provided only by the wast heat from the lights.

Plumbing Systems: In the standard building industry division of responsibilities, plumbing systems include all the nonheating piped systems (except sprinkler systems, which have unaccountably slipped into the heating and ventilating family). The most obvious are the hot and cold water systems and the sewage systems; but this broad jurisdiction also includes storm drainage, oxygen systems, vacuum systems, waste disposal, compressed air, distilled water, chilled drinking water, and a number of other process transmission pipings for chemicals, liquids, and gases of various kinds. Each of these systems has energy components, of course. Energy is required to heat, cool, and pump the various substances or to refine and produce the substance that is being carried in the pipes - distilled water and ground-up garbage, for example.

ENERGY INEFFICIENT BUILDINGS

In order to build energy-conserving homes, it is important to understand what combination of design, operation, and construction result in the greatest energy use, so that conservation efforts can be concentrated where they will do the most good. Generally, the greatest energy savings in residential buildings can be attained through reduction of air infiltration, primarily related to windows and doors, followed closely by the reduction of conductive heat transfer through the walls and windows (Figure 2-2).

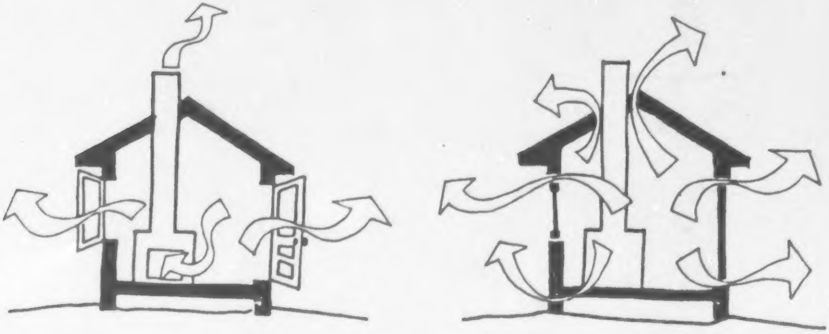


Figure 2-2: Openings

Sun Orientation

During the planning phase of dwelling design, attention must be given to orientation of the house as well as to its design. In order to achieve proper building orientation, many factors must be taken into account. The topography, noise levels, scenic views, concern for privacy, and the climatic factors of wind and solar radiation are all important and have a direct bearing on the vivability of housing.

The most complicated and often ignored factor affecting orientation is solar radiation. There are many variables to take into account. The wind, seasonal changes, and regional climatic differences in the United States makes this a difficult subject to discuss. For example, in northern latitudes where the air is generally cool, there is a need to orient the building toward the sun, but in southern regions, the axis of the building should be turned to avoid direct solar radiation and oriented toward cooling breezes instead. In the more temperate zones, where winter heating and summer cooling are both important, a dual role is required of the structure, and orientation often becomes a more difficult and critical factor to consider.

Generally, for best living conditions (warmth in winter, coolness in summer), principal facades of buildings should face south. In cool regions the optimum orientation (i.e., the direction the long side of the house should face) lies 12° east of south; in hot, humid regions, 50° east of south is desirable; in hot, arid regions, direct southern exposure to 35° east of south is desirable; and in temperate regions, 17-1/2° east of south achieves a balanced heat distribution. The most troublesome orientation is toward the west. Walls facing into the direct summer afternoon sun absorb radiant heat at a time when the house may have already become overheated due to radiant heat from the sun and warm air outside. During the winter, the prevailing cold winter winds impinge on west walls in many locations. The chart below offers suggested sun orientations for residential homes.

SUGGESTED SUN ORIENTATIONS

	N	NE	E	SE	S	SW	W	NW
Bedrooms	x	x	x	x	x	x		
Living Room				x	x	x	x	
Dining Room			x	x	x	x	x	
Kitchen			x	x	x	x		
Library	x	x						x
Laundry	x	x						x
Play				x	x	x	x	
Drying Yard				x	x	x	x	
Bathrooms	x	x	x	x	x	x	x	x
Utility	x	x						x
Garage	x	x	x	x	x	x	x	x
Workshop	x	x						x
Terraces			x	x	x	x	x	
Sun Porch				x	x	x	x	

Walls and Ceiling

One of the important items that a builder should consider is the type of house to be built. Should the structure be a single-story or two-story dwelling or a combination? What shape should it be? At first glance it would appear that a two-story dwelling would have less heat loss than a one-story dwelling of the same square footage of floor space. This can be illustrated by taking the dimensions of a house and computing the total area of the exterior walls and ceiling, where insulation is required, and then comparing it to the sane house converted to a one-story dwelling.

a. Two Story: 36' wide; 24' deep; 15'9" high

Walls: (36')(15.75')(2) = 1134 sq. ft.
(24')(15.75')(2) = 756 sq. ft.
1890 sq. ft.

Ceiling: (36')(24') = 864 sq. ft.
2754 sq. ft.

b. One-story Rectangular, Short:
36' wide; 48' deep; 7'6 1/2" high

Walls: (36')(7.54')(2) = 543 sq. ft.
(48')(7.54')(2) = 724 sq. ft.
1267 sq. ft.

Ceiling: (36')(48') = 1728 sq. ft.
2995 sq. ft.

c. One-story Rectangular, Long:
72' wide; 24' deep' 7'6 1/2" high

Walls: (72')(7.54')(2) = 1086 sq. ft.
(24')(7.54')(2) = 362 sq. ft.
1448 sq. ft.

Ceiling: (72')(24') = 1728 sq. ft.
3176 sq. ft.

The total area of walls and ceiling in the two-story dwelling is less than one-story dwellings of comparable floor area. This would give the impression that there is less heat loss in the two-story house. If we examine the figures more closely, we will note that the total wall area of (a) is 1890 sq. ft., that of (b) is 1267 sq. ft., and (c) has a wall area of 1448 sq. ft. This data is significant for several reasons. First, we must consider the insulating capability of the structure. The typical maximum full thickness insulation used in 2'x4' walls is R-11, which limits the heat loss reduction per square foot to a fixed amount. Much thicker insulation can be used in ceilings, which means that ceilings have a potential for greater heat loss reduction. Thus, the one-story dwellings with the larger ceiling area, 1728 sq. ft., to which the greater amounts of insulation can be applied, can have less heat loss (at lower insulation costs) than a two-story house, which has the greater wall area. Of the two, a one-story, rectangular house with the least wall area can be expected to have less heat loss, all things being equal. This alone tends to offset, to some degree, the fact that the two-story dwelling has less total area of walls and ceilings.

The Temperature Difference: The temperature difference between the inside and outside of the home is the main factor in determining how much insulation should be used in the walls, ceilings, and floors. In the northern part of the U. S., where cold winters are the rule, more money would be spent in obtaining more and better insulation than in the south. In some regions of the country, the cost of fuel is especially high, and this too dictates the use of more insulation. Aside from the heating aspect, there is also the cooling side, which would also benefit from added insulation. So, in the southern states, insulation can reduce the cost of cooling more than it would reduce the cost of heating.

Insulation: There is no simple answer to the question of how much insulation should be used. The optimum amount of insulation depends on a number of factors, which very from city to city, such as severity of heating or cooling season, first costs of installing insulation, fuel and energy rates, etc. However, the most important factor to consider when determining the amount of insulation to install is the heat loss per square foot that is to be achieved.

Another important factor to consider when deciding how much insulation to use is the first cost compared to the amount of savings that will result in operating costs over the life of the house.

Workmanship is important also. The manner in which insulation is installed can have as great an effect on heat loss or gain as the insulation itself.

In order to understand insulation, one must be familiar with the terminology of heat transfer. The conducting or insulating properties of different materials are rated using three factors. Actually, all three factors give essentially the same information, but they are used in slightly different ways. The proper understanding and use of these factors can help in selecting everything from basic building materials to complete walls, ceilings, and floors. The heat transfer factors are represented by the letters K, U, and R. At least one of these letters will appear in a variety of tables and charts that list the insulation properties of either basic building materials or standard structures already containing various types of insulation.

For convenience in comparing and working with these factors, all are based on a one-square-foot section of the material and on a one-degree temperature difference between surfaces. The thickness of the material may vary, but it is always listed in the table with the heat-transfer value.

The K Factor: The K factor is a conduction factor that tells you how much heat energy will pass through a piece of insulating material. The K factor is given in Btu per hour for one square foot of surface area, and a temperature difference between surfaces of one degree. Doubling either the temperature difference or the surface area will double the heat conduction, but doubling the thickness of the material will cut the heat conduction in half. In other words, K factors for any thickness material covering any size area and for any temperature difference can be used. Just multiply the K factor by the actual temperature difference and by the surface area, and divide the K factor by the proportionate increase in thickness. Thus:

$$\frac{(\text{K Factor})(\text{width})(\text{length})(\text{temperature difference})}{(\text{increase in thickness})}$$

is the heat conduction in Btu per hour. Be careful when using any of the heat transfer factors that careful note is made of the thickness of the material given in the table. Often the thickness is given for standard product sizes, but in other cases the thickness is for just one inch. All building materials have their own K factors. Materials that conduct heat more rapidly have higher K factors than materials that insulate well. So, when comparing K factors, the lower the K factor, the better.

The U Factor: The U factor is a universal factor because it applies to wall construction rather than to specific materials. If the wall construction is known, then the various K factors for each material could be used to find out what the heat conduction would be through the wall. But this approach would be rather tedious, and it mught not be very accurate either. If available, the U factor is the one to use because it often takes into account the effect of wind speed and surface finishes on each side of the wall. Like the K factor, the U factor is also expressed in Btu per hour for a one-square-foot area of wall, and a one-degree temperature difference. Knowing the U factor of a wall allows one to figure what amount of heat is escaping. Then the U factors of different wall constructions can be compared to determine what type of construction has the lowest heat conduction and, therefore, the best insulation properties. Knowing the U factor also helps in quickly determining the heat load of a home, since the same Btu are used in calculating heat loads. To find the U factor of a wall from the K factors of each material in the wall, use the following formula:

$$U = \frac{1}{\dfrac{\text{thickness of A}}{\text{K factor of A}} + \dfrac{\text{thickness of B}}{\text{K factor of B}} + \dfrac{\text{thickness of C}}{\text{K factor of C}}}$$

where A, B, and C are the materials in the wall. It is easy to see that this method of figuring the heat loss through a wall could become fairly cumbersome if a large number of materials are involved. For this reason, charts and tables have been prepared for complete walls.

The R Factor: The R factor is a resistance factor that tells how much a a given material resists the flow of heat through it. The R factor differs from the K and U factors in that a large R factor is better than a small one. In other words, the larger the R factor, the better the material resists the flow of heat. Most insulation materials have R factors printed on them. Building specifications will often list an R number for the insulation, and leave it up to the contractor to meet the requirements with the most economical materials availabe. The R factor is just the reciprocal of the U factor; that is, R = 1/U and U = 1/R.

Walls: Adding insulation to a wall will increase its R value or decrease its U value. In either case, the amount of heat escaping through the wall will be reduced. Adding 1 inch of insulation to an uninsulated wall will reduce the heat loss through the wall by 45-50% Adding two inches of insulation will reduce the heat loss by 60-65%. Adding three inches will cut heat loss by 70-75%, and adding four inches will cut heat loss by 75-80%. All of these quoted percentages depend on the particular type of insulation used, and on the construction of the wall before insulation is installed, but they represent typical figures.

It now becomes evident that adding more and more insulation has less and less effect on the percentage decrease in heat loss through the walls. For most applications, there is little benefit to be gained by adding more than four inches, since the added cost generally outweighs the benefits received in fuel savings. The best approach is to use better insulation rather than thicker insulation.

The addition of insulation to the walls, ceilings, and floors of a home reduces heat transfer - conduction, convection and radiation. Air is actually a very poor conductor of heat, even though it is able to transfer large amounts of heat energy by convection. The trick is to prevent the air from moving or circulating, and this is the way most foam, spum or batting insulation materials work. Some insulation, such as plastic foam and closed-cell insulation, actually creates dead air pockets by holding the air in sealed bubbles. Other insulation, such as batting and spun fibers, merely prevents the air from circulating freely. In either case, the motion of the air is drastically reduced, and only a small amount of heat is transferred by conduction through the air.

Good insulation has a high resistance to the conduction of heat through the wall. Even though convection may be a significant factor of heat transfer within the wall cavity, the insulation properties of the wall itself are treated as a conduction effect. Therefore, the addition of insulation with the wall acts to lower the conduction of heat through the wall.

Even some of the best insulating materials can become rathre poor insulators if allowed to get wet. The problem with moist air is that it can condense, and saturate some insulations, permitting the water, which has a very high heat conductivity, to transfer heat energy through the wall. Even worse, the presence of water or high amounts of moist air can rot and warp wooden beams and paneling. In particularly moist locations, such as basements or other masonry walls, the best vapor barrier is obtained by using large sheets of plastic installed directly against the masonry wall. Since concrete and cement-block walls are fairly poor insulators, it is a good idea to use at least some insulation behind the paneling in basements.

Basement walls above ground level are treated as exposed walls, but walls below ground level are exposed to ground temperature rather than ambient air temperature, and therefore, different calculation techniques are required. This will be discussed subsequently in connection with floors.

Some insulations, like fiberglass and rock wool, have a polished reflective surface on one side of the insulation. When you install this type of insulation, make certain that the reflective material faces into the house. Also, this type of insulation comes with a 1/2-inch flap at each side, so that the insulation can be stapled to the sides of the studs. Be sure you staple often enough to get a vapor-tight seal, and also so that there is a 1/2-inch air space between the face of the insulation and the insude sheathing of the wall. The reason for the 1/2-inch air space is that the shiny material on these insulators reflects back any radiant heat trying to enter, and an air space is required to do this. Since a 1/2-inch air space is also a fairly good insulator against conduction, the heat must then cross this space by convection (see Figure 2-3). Thus, the best application of these reflective-faced insulators is under the floor, since heat will have the greatest difficulty convecting across an air space in the downward direction. The next

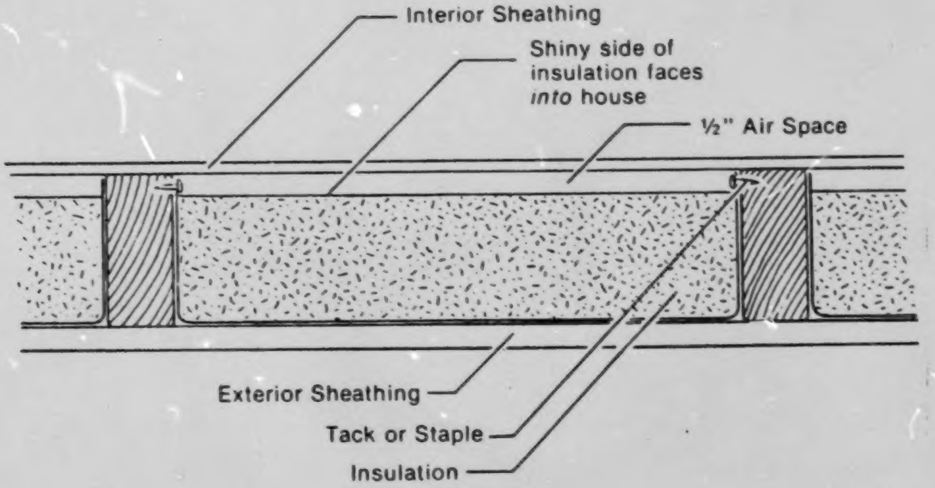


Figure 2-3: Looking Down on Stud Wall From Top - Using Reflective-Faced Insulation

best application is in walls, where the 1/2-inch space then insulates about as well as the same thickness of fiberglass would. The least effective application is in the ceiling, because the heat easily convects across the air space in this case.

On fiberglass or rock wool insulators, do not compress the material when installing. Buy the proper thickness and then let the material fluff-up with air before you staple it is place. Compressing only reduces the insulation value, as there are then fewer trapped dead air spaces in the material.

Ceilings, Attics, and Roofs: Insulating the ceiling of a house is extremely important. As much as 75% of the heat lost in a house is through the ceiling in the winter, so obviously it is important that this area be well insulated. Insulation in the ceiling will hold in the heat, which has a tendency to rise and escape through the ceiling into the attic space. In the summer, the heat flow reverses and extremely hot temperatures in the attic warm the room in the living area below.

For most applications, 6-10 inches of insulation is needed to prevent excessive heat gain or loss through the ceiling. Again, this will depend on the area, winter and summer design, temperatures, and other factors. More than 10 inches of insulation (R-30) usually costs more than the extra insulation is worth, but this varies. Twelve inches of insulation (R-38) is justified in some northern states where fuel costs are especially high. There are several different ways that the ceiling can be insulated, including blown-in fiberglass, batting insulation, or a combination of insulation types.

There are other ways to reduce the energy loss through the ceiling besides insulation, although this is the most important. One way is to lower the temperature of the attic above the living area of the house. When the attic is cooler, less heat will be transferred into the rooms below, and the air conditioner will have less of a load. The temperatures in attics can often exceed 125° F, and this adds a considerable amount of heat to the living space.

Where there is an unused attic, it's very important to provide ventilation. This will help dissipate the moisture that gets up through the ceiling in winter (keeping the insulation and attic joists and rafters dry) and also help in summer to prevent the build-up of attic heat. Usually a 1-foot-square vent is placed on opposite sides of the attic wall to do this.

The attic temperature can also be lowered by installing an automatic fan. Just installing vents at each end of the attic will often allow enough air circulation to lower the temperature of the attic quite a bit, and forcing the ventilation with a fan can lower the temperature even more.

The color of the roof has an effect on the amount of heat gain in the house. An important thing to remember here is that heat gain is undesirable in the summer, but it is desirable in the winter. This presents somewhat of a dilemma for the homeowner. While a dark-colored roof will absorb sunlight and add some desirable heat to the attic in the winter, this same dark roof will add heat to the attic in the summer, when it is undesirable. A light-colored roof will help reflect the sun's rays and leave the attic somewhat cooler than a dark roof in the summer. From the standpoint of energy conservation, a light-colored roof is recommended, because most homes stand to benefit more in summer than in winter. This is purely an energy-saving suggestion; however, since design or style will probably have more to do with the color and type of roof selected for a home than matters of energy conservation.

Floors and Basements

Building floors are often exposed to ground temperature rather than ambient air temperature, and therefore require different calculation techniques, depending upon the type of building foundation.

Foundations: The foundation supports the load or weight of the home, keeps it from settling into the soil, and prevents it from blowing away. In cold climates, the foundation also protects the home from the effects of the expansion of the ground due to frost "heaves". The kind of foundations commonly used in any area will depend primarily on the kind of soil or ground conditions existing there, and the amount of moisture in the ground. There may be a variety of foundation types in any area, depending on the geographical region and the conditions of the soil. Structures without a basement can have any one of several foundations.

Pier and Post: Pier and post foundations are posts built up on footings. These posts then support a platform, which holds the rest of the house.

Continuous Wall: Continuous wall foundations are poured concrete or concrete block wass resting on the footings, to form a continuous wall around the outside of the home. In homes with full basements, the continuous foundation wall is full height. Such basements usually also have a poured concrete floor.

Crawl Space: Between the "pier and post" and "continuous wall" foundations and the rest of the home there is usually a "crawl space", so named because of the way one has to maneuver around in it. The floor of such a crawl space is normally bare ground, which can create moisture problems and often should be covered by a ground cover vapor barrier.

Heat Loss: The heat loss through floors over unheated basements and crawl spaces is calculated using the following equation:

$$h = UA\,(T_R - T_A)$$

where h is the heat loss rate, Btu/hr.

U is the heat transfer coefficient of the wall, $\mathrm{Btu/(hr\text{-}ft^2\text{-}{}^oF)}$

A is the area of the wall, $\mathrm{ft^2}$

T_R is the room temperature, ^oF

T_A is the outside air temperatire, ^oF.

The U-value of the floor is calculated by summing the R-values of the floor materials. The design temperature difference to be used in the equation is the inside temperature minus the design ambient air temperature. If the floor is over an unheated basement, use one-third of design temperature difference in the heat loss calculations. If the floow is over an unvented crawl space with insulated walls, use one-half the design temperature difference. If the crawl space is vented or otherwise open to the outside, use the design temperature difference.

Slab-On-Grade: The slab-on-grade is a concrete slab poured directly on the ground, with the foundation extending to below the frost line. This type foundation can also have moisture problems, if condensation forms on the slab during hot seasons. Since the slab itself has a relatively low R-value/ high U/value, and sits directly on the ground, a considerable amount of heat loss may occur through the edges of the slab. Though the slab does not lose much heat into the ground below it (because the ground stays relatively warm throughout the course of the heating season), its edges are exposed to colder outside temperatures. Because the rate of heat flow is accelerated by the larger differences in temperature, the heat loss which occurs through a slab tends to be from its sides.

If the outside edge of the slab is at or above ground level, that edge is exposed to the prevailing air temperature rather than to the ground temperature. During cold seasons, the air temperature is usually lower than the ground temperature, which, below the frost line, rarely goes below 40-50° F. Heat can, therefore, be conducted from the perimeter floor area, through the slab, and out to the cold air.

The heat loss rate from a concrete slab-on-grade is calculated on the basis of exposed edge length rather than on floor area:

$$h = U'L\,(T_R - T_A)$$

where h is the heat loss rate, Btu/hr
U' is the heat transfer coefficient per linear foot, Btu/(ft-hr-°F)
T_R is the room temperature, °F
T_A is the outside air temperature, °F.

The U' values for use in this equation are as follows:

Insulation	U'
1" x 24"	0.21
1" x 12"	0.46
None	0.81

Perimeter Insulation: The term perimeter insulation applies to insulation placed along foundation walls and under concrete floor slabs. Several situations exist which need attention, such as a concrete slab on level ground or a slab in a basement where one side opens to the outside. For the slab on level ground, you will want to insulate around the outside of the foundation wall. In cases like this, where fire isn't a hazard, the high insulation value of the plastic insulations like polyurethane can work to your advantage. Normally only an inch or so of insulation is placed around the foundation. However, studies have shown that more heat escapes in northern areas than might be expected, so a 2- to 3-inch thick sheet placed all the way down to the base of the foundation is recommended (see Figure 2-4).

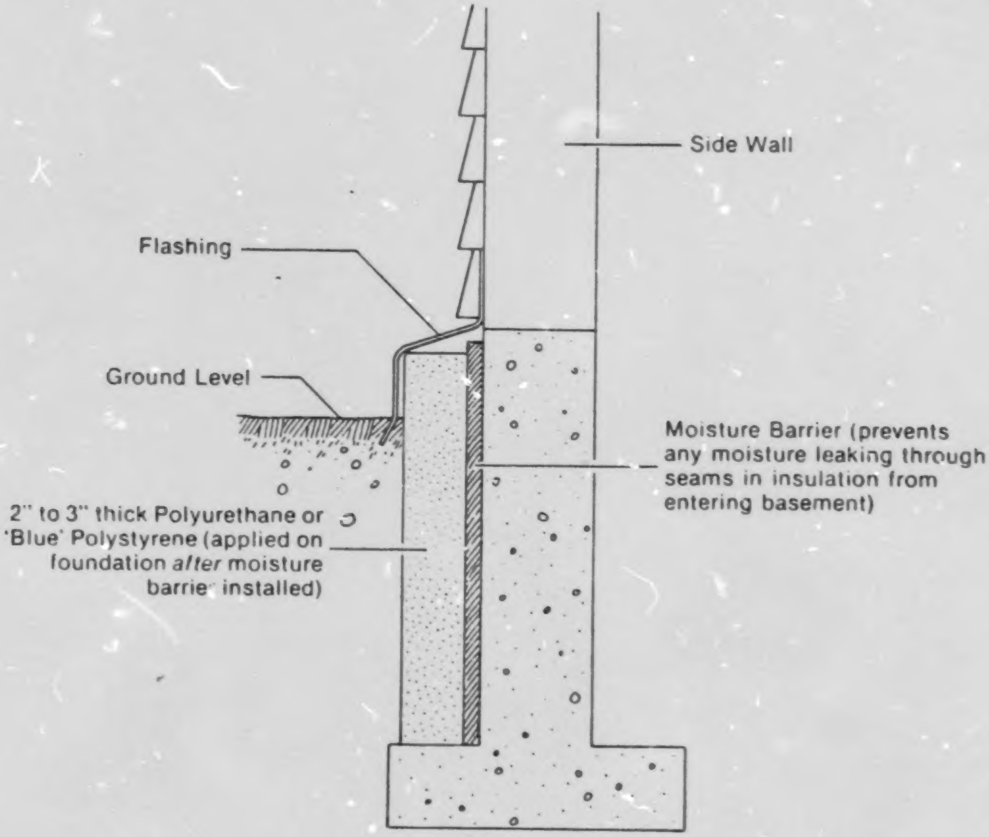

Side Wall
Flashing
Ground Level
Moisture Barrier (prevents any moisture leaking through seams in insulation from entering basement)
2" to 3" thick Polyurethane or 'Blue' Polystyrene (applied on foundation *after* moisture barrier installed)

Figure 2-4

In cases where perimeter heating is accomplished via ducts placed within the floor slab, a 1-inch layer of insulation stretching from the edge of the slab about 3 feet inward will ensure that heat moves into the room and not down into the earth below the slab (see Figure 2-5 on the following page). A 1-inch insulation strip is also used to separate the slab from the foundation wall, and in this case, the insulation is placed inside that part of the foundation wall that is below the floor slab. In extreme northern areas, there are alternate designs.

When polyurethane is installed, no protection from moisture on the outside of the insulation is necessary, as this plastic material is also a vapor barrier. However, moisture can leak through at those points where these

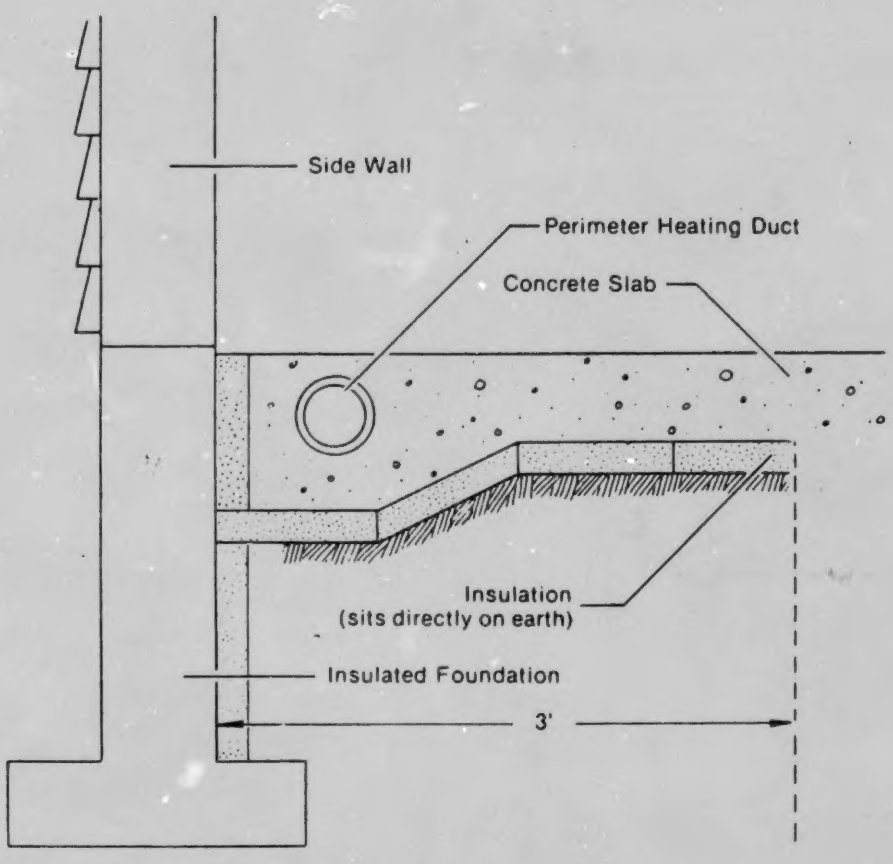

Side Wall
Perimeter Heating Duct
Concrete Slab
Insulation
(sits directly on earth)
Insulated Foundation
3'

Figure 2-5

insulation boards meet. Hence, it is necessary to install a vapor barrier to the outside of the foundation wall before you put on the insulation boards. For those parts of the insulation which are exposed between the ground and the beginning of the side wall, run a piece of flashing from behind the wall and down over the front of the insulation to keep moisture out. (See Figure 2-4).

In the case of a basement with one side open to the outside, the perimeter insulation need be applied to the foundation wall only on the exposed side. However, contrary to what many people believe, the three other partially or fully submerged basement walls will lose large amounts of heat unless insulated. If the wall is fully submerged, you can run insulation down its entire length and use flashing for exposed areas at the surface, as outlined above. For a partially buried wall on sloped ground, the same basic procedure applies except that more care must be taken for the larger exposed wall area in this case. Here, unless the polyurethane is protected from the sun, it will break down to a powder which is blown away by the wind. To protect this insulation, and for appearance's sake, apply a cement-stucco plaster to the surface at any exposed point.

Doors and Windows

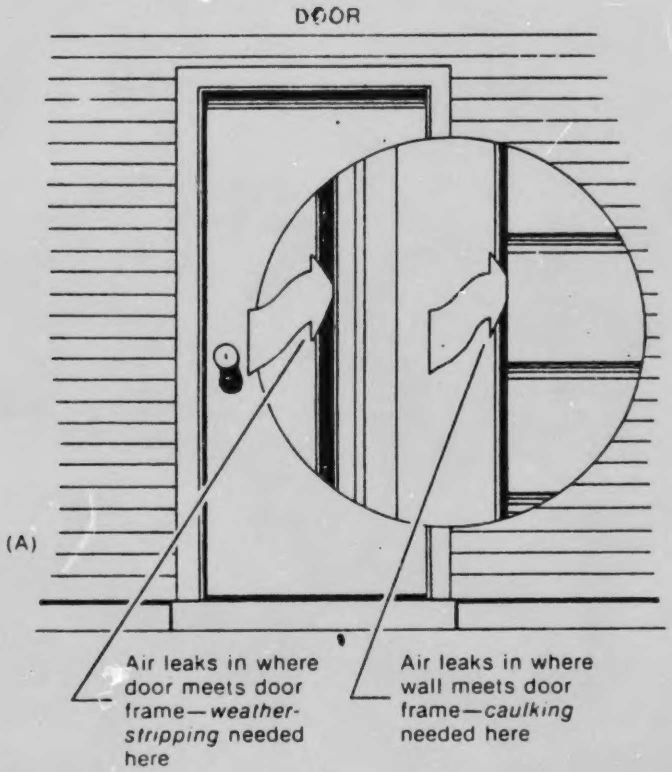
Doors and windows in your home can account for some 50% of the heat loss. An infiltration problem occurs because of cracks where the door frame and where the sash and wall meet the window frame (see Figure 2-6, which is shown on the following page).

A conduction problem also occurs because glass and most doors are not good heat insulators; hence, warmth goes through them very easily.

Doors: Exterior doors are set within door spaces built in the frame of the home. The space defined by the vertical studs on each side of the door space and the header which they support is lined with door jambs (a head jamb and two side jambs). The space between the frame of the door and the door jambs is maintained by blocking, as illustrated in Figure 2-7 in subsequent pages. This technique allows the jambs to be leveled independently of the frame, but, the space left open provides a direct passageway for infiltration around the door. (See Figure 2-8, which is shown in the following pages). The door itself is hung on one of the side jambs.

If a door has been properly hung, the space, or clearance, between it and the frame will have been held to a minimum. The door should close against door stops on both edges and at the top. These stops reduce infiltration around the closed door. At the bottom, the door should have only a minimum clearance over the threshold. It is, of course, impractical to install a door stop on the floor, but a variety of substitute sealing devices, such as weatherstripping, are available.

Once the door has been properly hung in the jambs, an inside trim, called casing, is nailed to the jambs in such a way that it extends over the space


DOOR
(A)
Air leaks in where door meets door frame—*weather-stripping* needed here
Air leaks in where wall meets door frame—*caulking* needed here

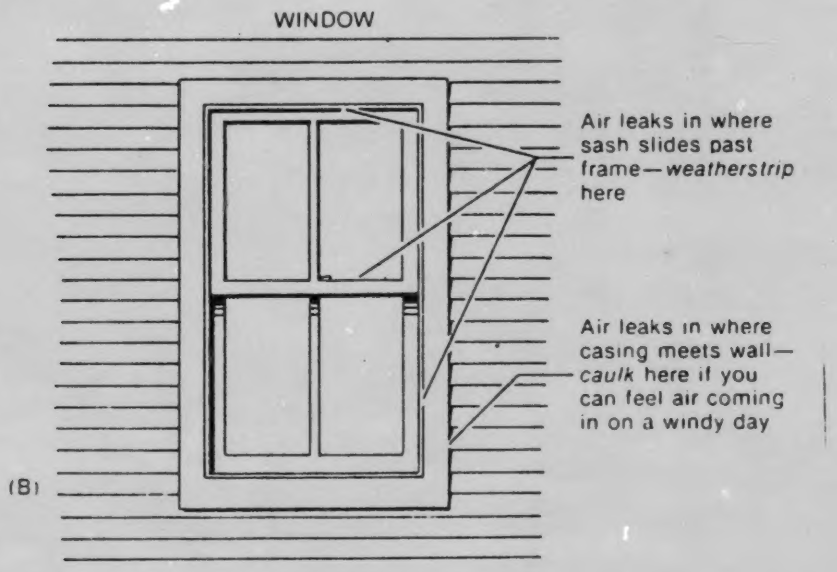

WINDOW
Air leaks in where sash slides past frame—*weatherstrip* here
Air leaks in where casing meets wall—*caulk* here if you can feel air coming in on a windy day
(B)

Figure 2-6

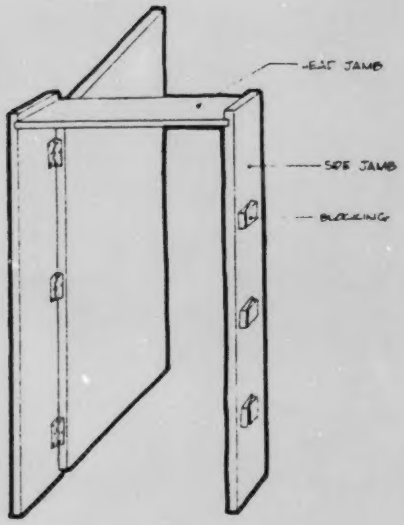


Figure 2-7: Door Jamb

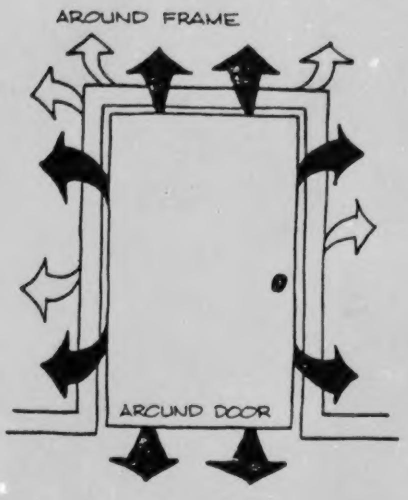


Figure 2-8: Infiltration Around Door

between the jamb and the door frame. An exterior trim (sometimes called (brickmold) is sometimes nailed in place on the outside, extending over the space and onto the siding.

When closed, a door acts as part of the envelope of the house. Conductive losses always occur through it, depending on the material of the door. Commonly, doors may be of solid wood, a plywood facing over a solid, hollow, or fiber core, or metal sometimes over a core of rigid insulation. Other kinds of doors may be common in some regions. It is important to determine the door's material and the effective R-value or U-value. The folloring table gives representative U-values for various types of doors.

Solid Wood	No Storm	Wood Storm	Metal Storm
1"	0.62	0.30	0.38
1-1/4"	0.53	0.28	0.34
1-1/2"	0.47	0.27	0.33
2"	0.42	0.24	0.29

Metal Door	Mineral Fiber Core	Solid Urethane Foam Core	Solid Polystyrene Foam Core
1-3/4"	0.57	0.19	0.45

Weatherstripping: One of the most important ways that energy can be conserved in the home is by weatherstripping. Through weatherization, more heat is kept inside the house during the winter months and outside during the summer months. Doors should be located away from prevailing winds in cold climates and facing into the wind in warm climates.

Even the most inexperienced person can weatherstrip doors with little difficulty. There are several different types of weatherstripping that may be used, including adhesive-backed form, rolled vinyl with aluminum channel backing, foam rubber with wood backing, and spring metal.

Door shoes are good for stripping the bottoms of doors, and are useful with wooden thresholds that are not worn. Door shoes are very durable, but very difficult to install. The door must be removed and the required amount trimmed off the bottom edge. A vinyl bulb threshold is another possibility for weatherproofing the bottoms of doors. This type of threshold is especially useful when there is no threshold, or when the wooden one is worn out. It is difficult to install and the vinyl will wear out, but replacements are available. The vinyl bulb should seal around the bottom of the door when the door is closed.

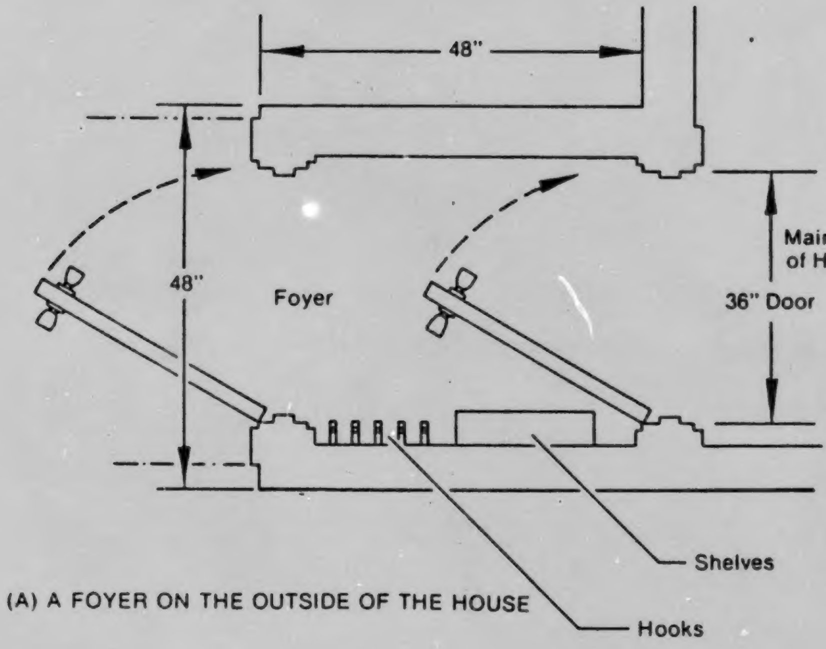
Another possibility for sealing the air leak under your door is the interlocking threshold. However, it is extremely difficult to install, and should be installed by a skilled carpenter. It does form a very good weather seal. Interlocking metal channels may also be used in weatherstripping doors. These are also difficult to install, because alignment is critical to achieving a proper seal. Fitted interlocking metal channel is an excellent weatherstripping. It forms an exceptionally good weather seal.

Flat thresholds are sometimes weatherized by installing a sweep. However, a sweep may drag on the carpet or rug. Some sweeps are installed on the inside of the door and some on the outside. Installation is very easy.

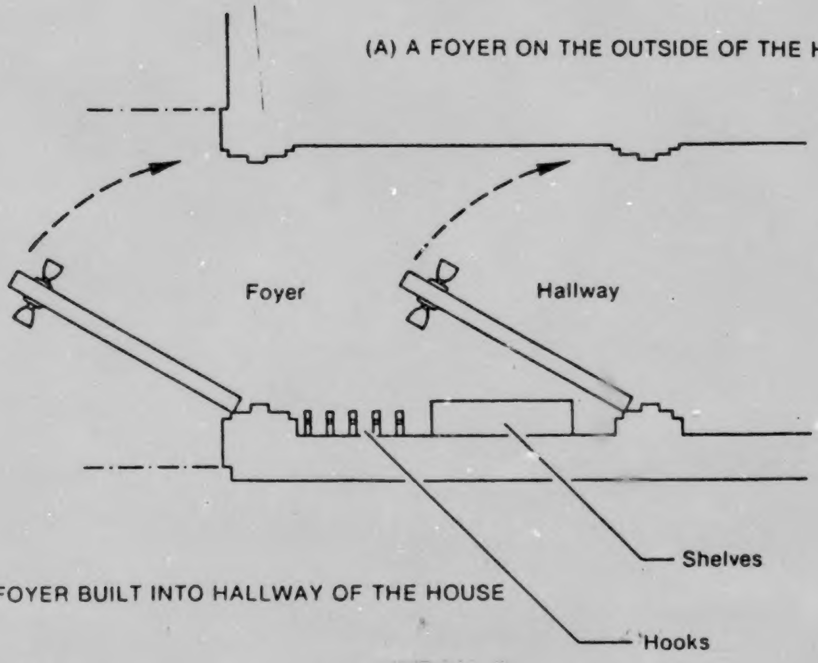
Storm Doors: Consider storm doors. While 10-15% of the purchase price of combination (windows and screen) storm doors may be saved if installed by the homeowner, such an installation is difficult unless one is a relatively skilled carpenter. When installed, a storm door (1) should open smoothly and fit tight; (2) should not have wide cracks around the door jamb (the seal should be as air-tight as possible); and (3) the exchangeable window and screen panels should fit properly and seal tight. Storm doors can be purchased that are made of aluminum, steel, or wood. Weatherstripping is very important if a storm door is to fulfill its function of reducing air leakage around doors.

Closing Off Doors: If you have more than one door in your home, try to get through the winter using only one. With the other(s) thoroughly weatherstripped and sealed, the savings and added comfort make the effort worthwhile. In winter, close off those doors on the windy side of the house, and, if possible, don't use a door on the leeward side either. The positive pressure on the windy side forces air into the house, and the low pressure of the leeward side will suck air out. Sealing up the door can be easy. First, weatherstrip all the way around, and don't forget to block air which comes in where the door meets the floor. If you really want to stop cold air infiltration, then tack a plastic sheet over the frame. A curtain or drape can be hung in front of the door and makes a pleasant appearance.

Air-Lock Foyers: You may want to consider an entrance foyer. These foyers act as air-locks, preventing the cold air from coming into the house each time the door is opened or closed. Another heat-saving feature of the entrance foyer is that the entrance door to the house faces a still air space. Hence, the air infiltration that normally occurs around the door will be eliminated. An air-lock foyer is easy to build. Since the purpose is to create a still-air space and minimize the cold air that comes in the house when the door is opened or closed, the best entrance foyer is also the least expensive - a small one! It's not even necessary to insulate the walls: just build a simple construction with the outer door weatherstripped to keep the wind out. The foyer can be placed just outside your present entrance door; or, if you have a long hallway, you might consider building it on the inside of the house. The outer door of the foyer should open out to ensure that in a fire no one could block the entrance door. Figure 2-9, shown on the following page, illustrates the two types of air-lock foyers described here.


48"
48"
Foyer
Main Part
of House
36" Door
Shelves
Hooks

(A) A FOYER ON THE OUTSIDE OF THE HOUSE


Foyer
Hallway
Shelves
Hooks

(B) A FOYER BUILT INTO HALLWAY OF THE HOUSE

Figure 2-9

Windows: For the windows, several considerations are required. Here, the air infiltration around the window and the conduction of heat through the glass are even more important than with doors. (See Figure 2-10). Moreover,

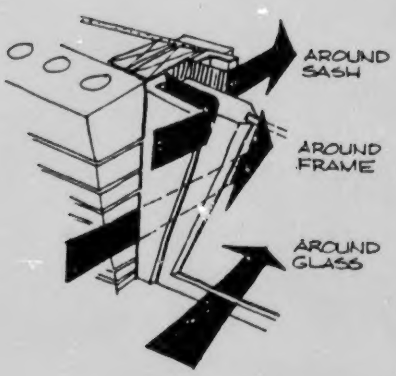

AROUND SASH
AROUND FRAME
AROUND GLASS

Figure 2-10: Infiltration Around Windows

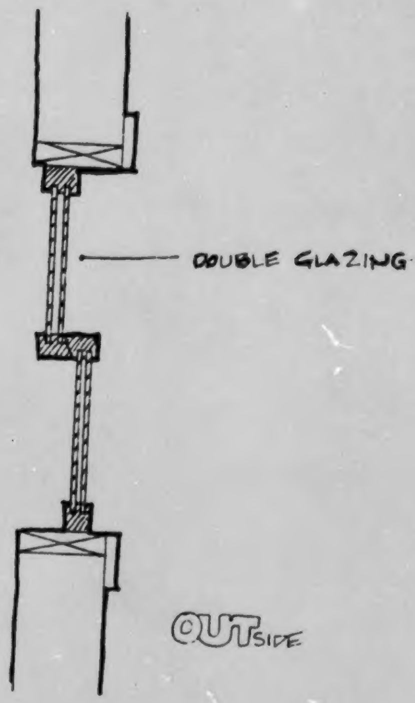

DOUBLE GLAZING
OUTSIDE

Figure 2-11: Thermal Window

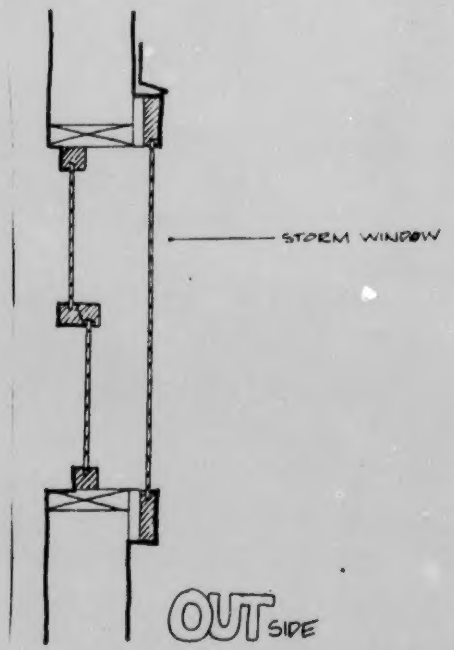

STORM WINDOW
OUTSIDE

Figure 2-12: Storm Window

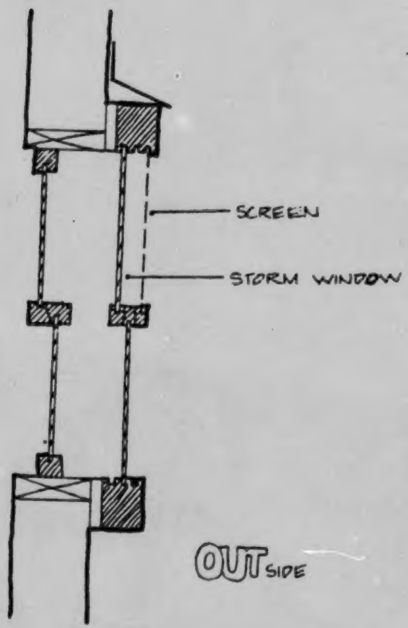

SCREEN
STORM WINDOW
OUTSIDE

Figure 2-13: Combination Windows

the solution of these problems must be accomplished in a way that still allows us to provide the light, view, and summer ventilation we need. Most building codes require a minimum glazed area of 10% of the floor area. The window area of most dwellings is normally about 15% of the floor area.

Windows come in many shapes and sizes; some of them open and some of them do not. Regardless of how they open, however, most windows are installed into the frame of the home in much the same way doors are. The opening created by the header on top, jack studs on the sides, and rough sill on the bottom, holds the window jambs and finish sill. Blocking is employed to level the jambs within the rough opening, and trim (casing) is then placed on both sides and on the top of both the exterior and interior surfaces, thus covering the space between the window jambs and the rough framing of the window. As in the case of doors, this space is a direct passageway between the outside and the inside of the home, and should be caulked and/or stuffed with insulation. The bottom of the window is the finished sill, covered by the stool and trim (or apron).

Over time, a home may shift in the ground, and building materials expand and contract. In the process, cracks may develop between the sashes, between the finish sill and the rough sill, around the casing, and at any of the joists in the window construction. The glazing compound (used to seal the glass and the frame elements) can become brittle and crack or flake off. All these events can create unintentional space for air to flow into and out of the home.

Windows are constructed to be an integral part of the envelope of a home, and, therefore, they are subject to conductive heat losses. Since the resistance value of glass is low, it is imperative to minimize heat loss through windows. Although glass is a poor insulator (low R-value), it can provide heat gain into the home through the process of radiation. This heat gain can be beneficial during the heating season, but during the cooling season, this same heat can prove costly in terms of increasing the cooling load of the conditioned space. Therefore, it is important that the resident use additional glazing, reflection and absorbing films, shades, drapes, shutters, blinds, and overhangs selectively during the year.

Glazings: There are three common ways to reduce conductivity through windows. First, storm windows (see Figure 2-12, shown in the preceding pages), which are designed to fit flush to the exterior casing and to form a tight seal with the casing and the sill. In some parts of the country, storm windows are usually put up for cold seasons and taken down (usually replaced with screens) for warm seasons.

Second, combination windows in which a storm window and screen are both contained in one unit. With the change of seasons, one is lifted on its track out of the way and the other slides down its track and into position. Because the frames are flexible and thus influenced by climate conditions, it is sometimes difficult to keep the storm portion tightly sealed in place. A little care and proper maintenance can usually alleviate most of this problem. The combination window is illustrated in Figure 2-13, also shown in the preceding pages.

Third, double glass (Figure 2-11, in the preceding pages), in which two pieces of glass are installed in the sash itself. A spacer and sealer are used between the two panes, which are then attached to the sash as a unit. This unit is sometimes called thermal or insulating glass. To be effective, the two panes of glass should be separated by at least half an inch. Separating the panes by greater than three-quarters of an inch has little additional insulating value.

It is important to note that, though the use of these windows can reduce conductivity through the sashes, it will have no effect on infiltration around the windows.

Weatherstripping: Weatherstripping a window is similar to weatherstripping a door. The simplest method of obtaining good weatherization for your windows is simply to tack sheets of plastic over the outside of your windows. If you prefer, the plastic can be taped over the inside of the window. Whether you install the plastic on the inside or on the outside, be sure that all possible air leaks around the moveable parts of the window are blocked. Inside installation is more desirable because the plastic is less likely to be damaged. Inside installation is also easier. In either case, the plastic should be stretched tightly. In addition to better appearance, tightly stretched plastic will be less susceptible to deterioration.

Energy Conservation: If you are serious about lowering your heating bill, more has to be done to contain your home's heat than simply adding some kind of storm window. In Figure 2-14, a comparison is made between the insulating effect provided by window glass and a stud wall. The units of "total resistance are used to measure the relative insulating value of combinations of materials to heat flow. As you can see, even insulating windows still lose heat eight or nine times as fast as the same area of wall does. While you benefit from the view, and the natural light and heat from the windows during the day, something has to be done at night to help retain this heat. Once the sun sets, about half the heat you lose from your home escapes around and through the windows. Depending on the climate, there are several approaches to

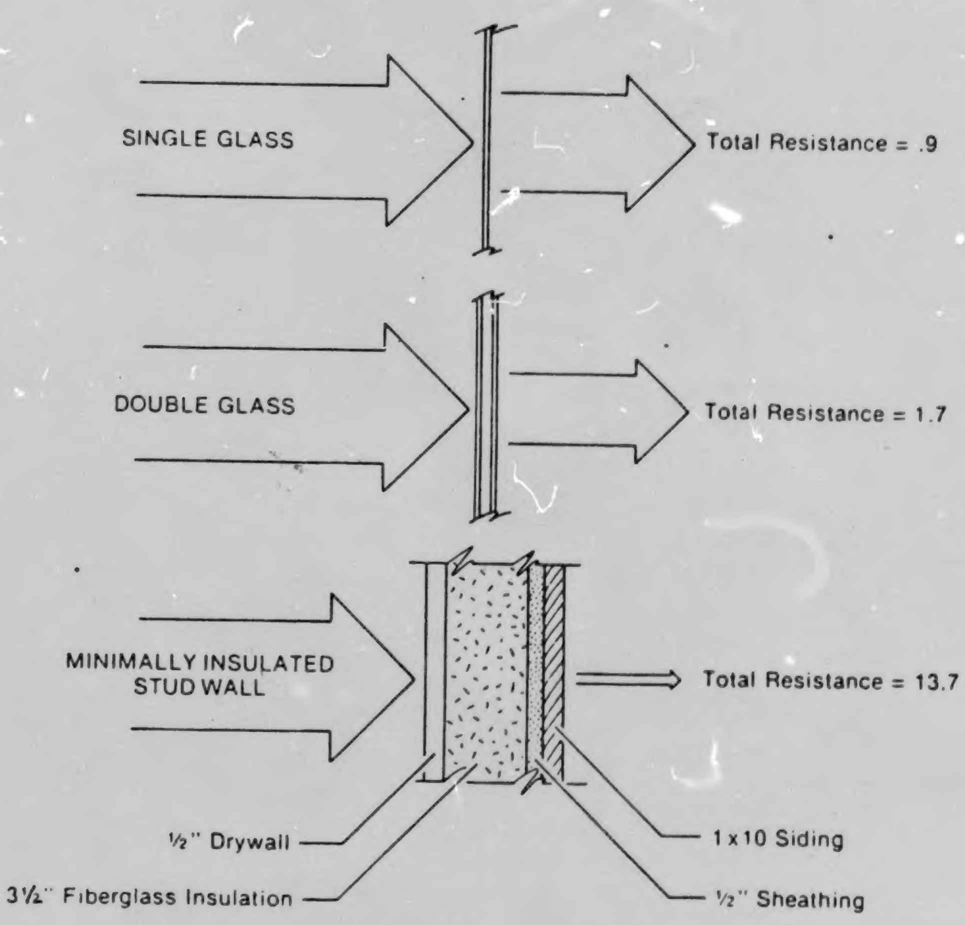

SINGLE GLASS
Total Resistance = .9
DOUBLE GLASS
Total Resistance = 1.7
MINIMALLY INSULATED STUD WALL
Total Resistance = 13.7
½" Drywall
3½" Fiberglass Insulation
1 x 10 Siding
½" Sheathing

Figure 2-14: Heat Loss Rates

movable insulation to cover the windows at night. As you think in terms of movable insulation, you'll find that you need not be bound to an energy-conserving strategy based on small window areas that deny you essential outdoor light and vision.

There are as many types of thermal shutters and curtains as there are inventive minds to dream them up. Any way that you can move a shield of thermally resistant material to seal your windows at night and hang back out of the way during the day will be effective in saving energy. Thermal screens or shutters have been successfully employed on both the insude and outside of the window.

Even ordinary curtains make a room warmer. The surface temperature of a curtain is significantly higher than that of its accompanying window glass; and, surprisingly enough, the timperature of a room's surfaces is more important to your comfort than the toom's air temperature. To make a curtain more effective, we must stop the air in a room from moving down across the cool glass and onto the floor (Figure 2-15). One way to cut down on this convective flow is to put a plywood box over the top of the curtain (see Figure 2-16). This prevents warm ceiling air from moving down across the glass, but a local convenctive air flow still develops. To eliminate this flow, we need to seal the curtain to the window frame on the bottom and sides, thereby making a pocket where the cool air is trapped.

Planning Efficient Windows: When planning a home's windows, you must find a balance between too much and too little window area. Windows anser some basic human needs, and having too few of them will make a home dark and uncomfortable. Too many windows, on the other hand, not only will up the initial cost of a home, but will continue to wear your pocketbook thin with increased monthly heating bills. Generally, the amount of window area on the north wall should be kept to a minimum if you want to build an energy-efficient home, as you get no direct sunlight into your home from these windows. The east and west walls deserve caution. To avoid overheating problems in the summer you must be sure that whatever glass is placed on these walls can be adequately shaded, even with the sun low in the sky. The south wall should have the largest area of windows. Here you can capture the sun's heat in the winter but can easily shade windows on this wall with an overhang. To provide an adequate but not excessive window area, you need to examine in detail your

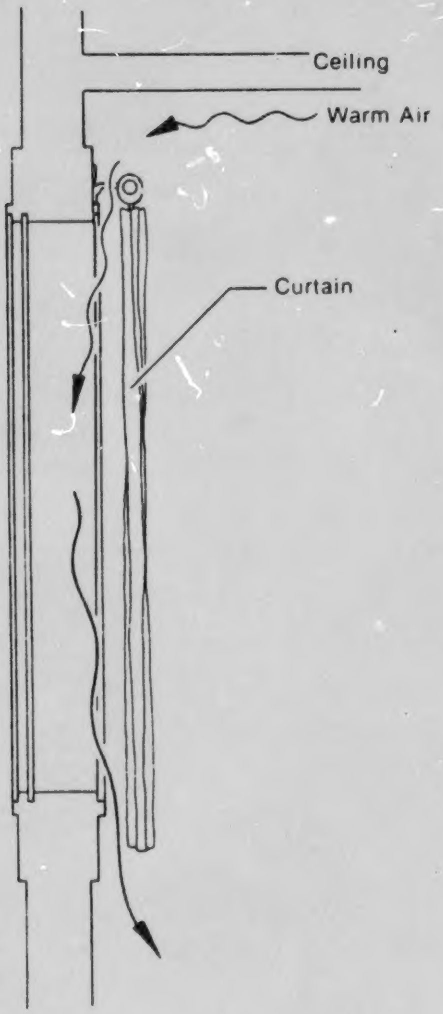

Ceiling
Warm Air
Curtain

Fig. 2-15: Convection at Curtained Window

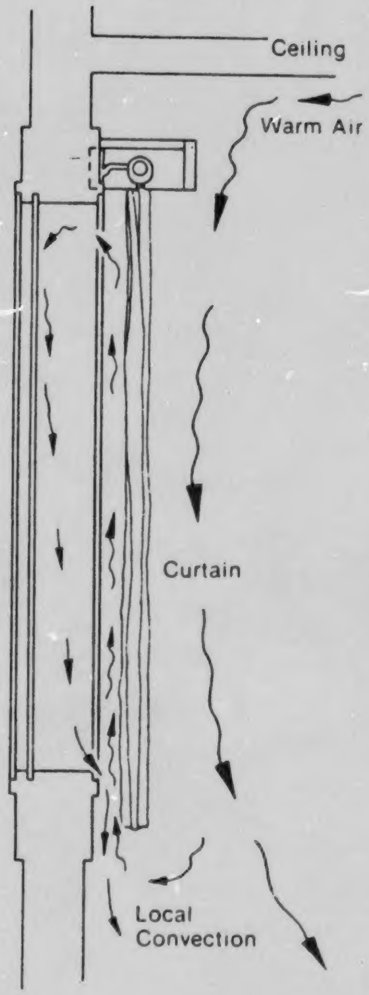

Ceiling
Warm Air
Curtain
Local Convection

Fig. 2-16: Convection with Top Cap Over Curtain

needs for both light and view. Some windows may be just for bringing in light, but before considering these, you should begin by planning the windows that are for viewing. These "viewing" windows may bring in all the light that is needed.

Vents and Infiltration

The envelope of a home has a number of openings. A few of these are intentional; most are unintentional; both serve as paths by which warm/cold air can enter (infiltration) or leave (exfiltration) the conditioned space. During the heating season cold air infiltration and warm air exfiltration can add to the heating load of the structure, while in the cooling season, warm air infiltration and cold air exfiltration can have the same effect on the cooling load.

A certain amount of air change is necessary in order to maintain generally safe air quality and to control moisture levels. Most homes, nonetheless, could be made considerable tighter than they are and still have enough changes of air (especially controlled changes) to meet ventilation needs.

Unintentional openings in the envelope may exist any place two structural components or materials meet. For example:

- Around doors and windows,
- Around the foundation,
- Around flooring
- Around walls
- Around ceilings
- Around chimneys, flues and vents, and
- Around heating, cooling, and hot water distribution systems.

Doors and windows have been treated in previous discussions and will not be included for further consideration.

Foundations: It may be difficult, if not impossible, to see all the places where openings might occur, either in the foundation or between the foundation and the framing of the building. But often you can feel for drafts with your hand, or use a smokestick. If it is a calm day, and detecting drafts is not possible, one can look for dry, broken caulk. By thinking about how the homes are constructed, you can visualize places where the greatest potential for unplanned openings may be. (Figures 2-17, 2-18, 2-19, on the following page, give some examples). If the foundation is made of poured concrete, openings are less likely that if it is made with concrete blocks, or stone and mortar. Major cracks (see Figure 2-20 on the following page) may indicate a serious shifting and weakening of the structure. The junction of the foundation and the building is always a potential site for cracks. Shifting soil and underground water exert pressure on the portion of the foundation embedded in

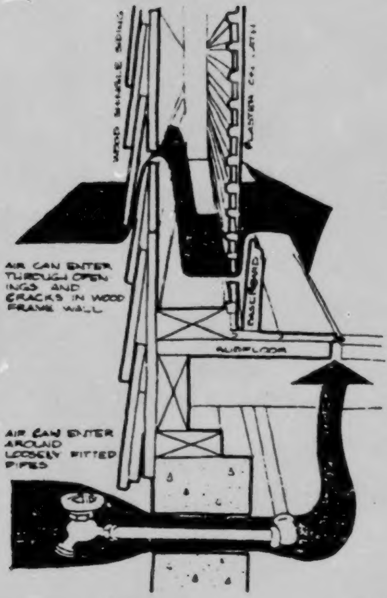

WOOD SHINGLE SIDING
PLASTER ON LATH
AIR CAN ENTER THROUGH OPENINGS AND CRACKS IN WOOD FRAME WALL
BASEBOARD
SUBFLOOR
AIR CAN ENTER AROUND LOOSELY FITTED PIPES

Fig. 2-17: Infiltration through Wall

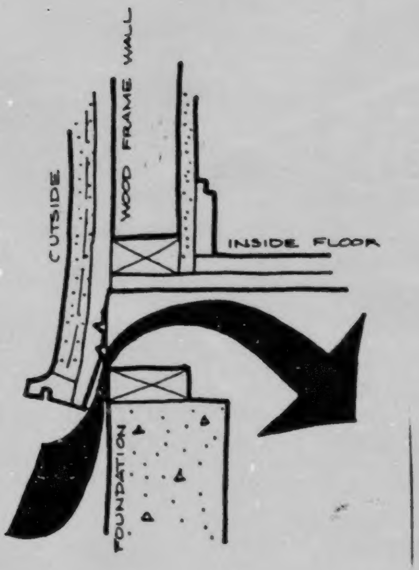

OUTSIDE
WOOD FRAME WALL
INSIDE FLOOR
FOUNDATION

Fig. 2-18: Infiltration through Wall Junction

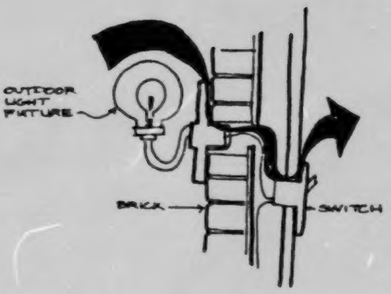

OUTDOOR LIGHT FIXTURE
BRICK
SWITCH

Fig. 2-19: Hard to Find Infiltration

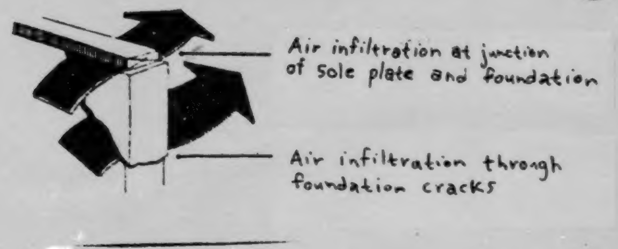

Air infiltration at junction of sole plate and foundation
Air infiltration through foundation cracks

Fig. 2-20: Structural Breaks

the earth. These pressures may crack the foundation. If the foundation moves within the ground as a unit, the pressure may be transferred to the home above. Since the building structure will offer some resistance, the weak link may be the junction of the building frame and the foundation.

Floors: The floors themselves may contain unsealed cracks. These are especially likely (Figure 2-21) at the junction of different parts of the floors, for instance, between rooms or where different flooring materials meet (such as in unfinished closets and cupboards). Since some floors do not have subflooring, a crack in the floor may extend directly into the space below. Depending on the quality of the construction, a similar situation may exist even with subflooring.

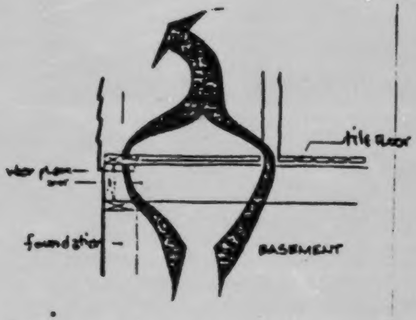


Fig. 2-21: Cracks in Floors

Finished flooring is installed flush to the sole plate of the exterior wall. The wall surface itself should rest flush on the flooring. Since this junction is usually covered by molding, it may not be possible to see whether or not there are cracks between the wall surface and the floor, or between the floor and the sole plate (Figure 2-22). If there is space for conditioned air to pass under the sole plate, it can move directly into or out of the room. Molding seldom makes an airtight seal. Similar cracks may also exist at the junction of interior walls.

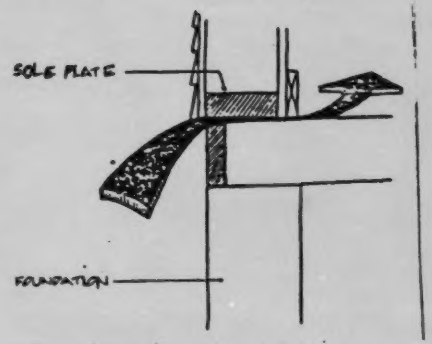


Fig. 2-22: Infiltration at Sole Plate

In addition to structural cracks, there are also intentional holes in floors to permit the passage of chimneys, pipes, ducts, and wires. Whenever a chimney passes through a floor, an empty space used to be left around it for fire safety (see Figure 2-23). This space is enclosed by a wood frame called a box, formed by putting a header on each side of the chimney between the floor joists. Since the hot chimney could ignite adjacent wood, a space is left between this box and the chimney. The sub-flooring and flooring are also kept away. Since chimneys often pass through walls or closets, these spaces may be hard to find, but it is very important to try to find and block the leakage around them.

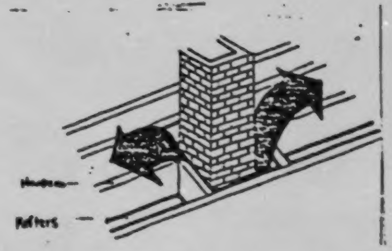


Fig. 2-23: Chimney Box Spaces

Other difficult-to-find yet important intentional openings are the holes cut for pipes and wires (see Figures 2-24 and 2-25). These generally run through inside walls, which are not usually insulated. Oversized holes are almost always cut to permit easy threading of the wire or pipe. When pipes or wires extend up into the attic, a hole must be cut for them through the top plate, in effect establishing a chimney between the basement and the attic. During the heating season, air entering a wall cavity from the basement is heated somewhat within that cavity by the conduction of heat from the adjacent rooms. This warm air then rises and passes into the attic and is replaced with cold air from the basement. In a cooling season, the same convection process can allow warm humid outside air from the attic to move into cooled living spaces.

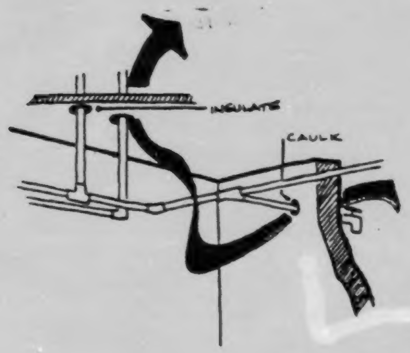


Fig. 2-24: Pipes Through Floor

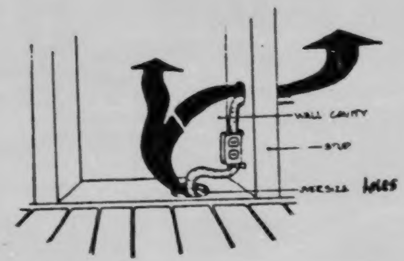


Fig. 2-25: Wires Through Floor

Walls: It has already been pointed out that some openings inside a wall cavity can produce a chimney effect. If, for example (Figure 2-26), the interior covering of a wall has an opening cut into it for an electric outlet

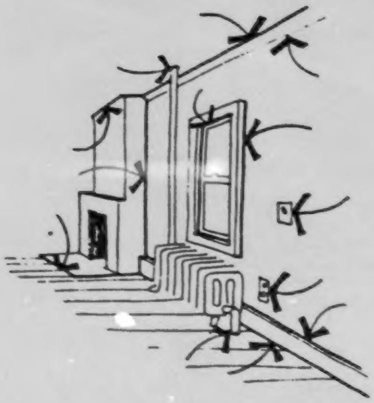


Figure 2-26: Potential Openings

or switch, unconditioned air in the cavity can enter the room, or conditioned air can pass through the opening into the cavity. Which of the processes occurs at any given time will depend upon the size of the openings and the relative air pressures in the cavity and the room, and on whether the primary energy demand is for heating or for cooling. In either event, energy is being wasted through infiltration and exfiltration.

Openings in an exterior wall surface, which are likely to exist if board siding is used with no sheathing underneath it, can also allow infiltration of outside air to the wall cavity (Figure 2-27). Air can sometimes leak into the cavity under the bottom boards.

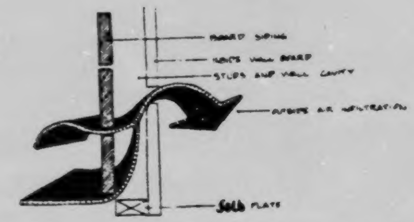


Figure 2-27: Wall Infiltration.

If the inside wall surfaces are tightly sealed, and insulation has been installed in the wall cavity, some of the air entering and leaving the cavity from the outside may be acceptable. Since the air will not infiltrate into the conditioned space, and convection currents will be retarded by the insulation, the small amount of outside air moving in and out of the cavity will help remove moisture and prevent condensation. On the other hand, if the wall is not tightly sealed from the inside of the home, the leakage of conditioned air into the cavity can have an adverse effect on energy conservation and moisture levels in the wall.

Ceilings: Important openings exist in the ceilings and attic floors, which must be blocked to prevent heat loss and moisture problems (see Figure 2-28 on the following page).

Ligut fixtures in a ceiling can be "recessed" (the surface of the fixture is flush with the ceiling) or "suspended" (the base of the fixture is flush with the ceiling). In either case, the electrical wiring enters from above the ceiling into a ceiling box (Figure 2-29) to which the fixture is wired. An opening is cut through the ceiling for either the attachment itself, or the passage of light. If the seal around this opening is not tight, air can also pass through it from the conditioned space into the attic. The problem is complicated by the fact that, in order to reduce fire hazards, insulation must be kept away from the fixture. The existence of an air passage and the absence of insulation can create a wide-open pathway for exfiltration, and severely reduce the cost-effectiveness of adding insulation in other parts of the attic.

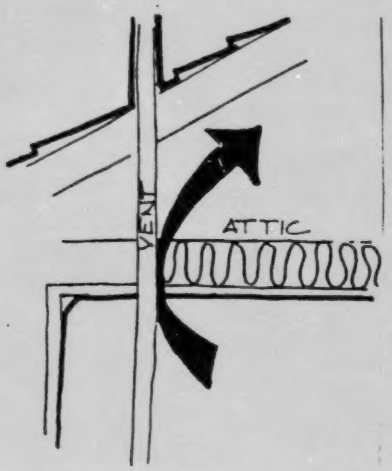


Fig. 2-28: Air Passes at Vent Pipe

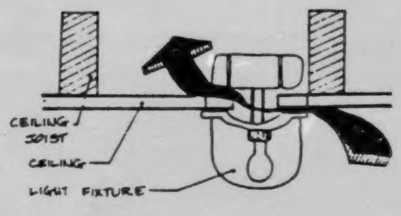


Fig. 2-29

Entrances to an attic may also present special problems. An unconditioned attic may have a trap door with a sliding cover (see Figure 2-30), a hinged trap door with a folding ladder, or no cover at all. In some older homes, where the attic was used for storage, as well as in homes in which the attic is "finished off" and conditioned, the attic is often reached by a set of stairs with a door at the top, bottom, or both. In regions with high heating demands, such an area should be insulated. If there is no closure, the movement of air through the wide open space can be significant, constituting a serious energy drain for both heating and cooling.

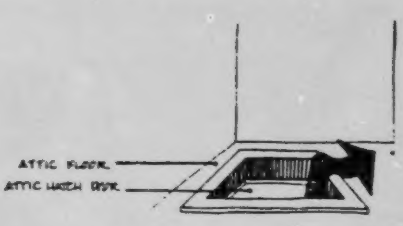


Fig: 2-30: Attic Doors

Chimneys, Flues, Vents: A flue is a pipe or shaft provided for the passage of smoke or hot gases. Chimneys serve the same function, and are actually brick or masonry sheathings around one or more flues. Vents, in residences, generally carry room-temperature air, which has been contaminated by cooking and other activities, to the outside.

The introduction of warm air into the attic during winter has two harmful effects. First, the warm air heats the attic, wasting heat. The second effect of air leaks is to carry moisture from the home into the attic; the cold roof surface can condense this water vapor, which may cause damage to the structure.

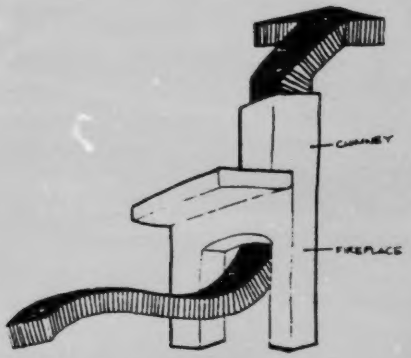


Fig. 2-31: Fireplace Heat Loss

The openings around vents and flues (where they pass through floors, walls and ceilings) have been discussed. An additional problem, however, is the opening within the structure itself - the chimney of a fireplace, for example, or kitchen range hood. (See Figure 2-31).

Whenever the fireplace is used, the damper must be opened. This allows for a direct pipeline to the outdoors. Moreover, while the fire is burning, the heated air in the fireplace moves up and out the chimney. Unfortunately, room air is drawn into the firebox and up the chimney at a rate of two to three times the normal infiltration level (Figure 2-32). Cracks around the fireplace frame and the wall also contribute to infiltration problems.

When the fire is dying, but before the damper is closed, warm room air still enters the firebox and passes by convection up the chimney and out. Most importantly, even when there is no fire at all, if the damper remains open or leaks, upward convection moves warm air out of the home. This process, known as the chimney effect, can draw out large volumes of conditioned air, which is then replaced by the infiltration of cold outside air.

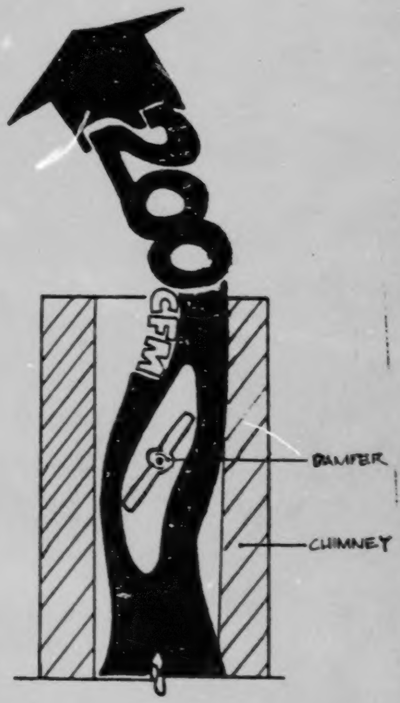


Fig. 2-32: Fireplace Damper

Closing the damper reduces but does not eliminate this problem, since the damper seldom makes a good seal, either because of soot build-ups on its sealing surfaces, or because it is warped from the heat of the fire.

Flues, (or stovepipes) for wood burning stoves can cause similar problems, thought some air-tight wood stoves can, when used with an effective damper, greatly reduce the exfiltration which would otherwise result from the chimney effect. (Figure 2-33).

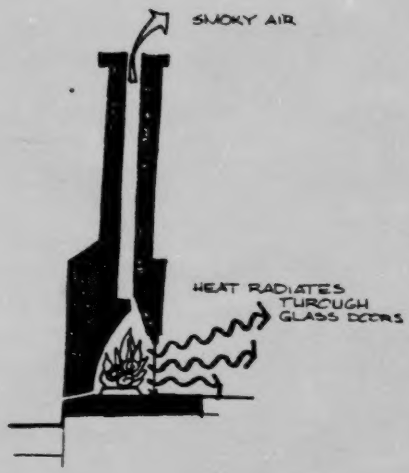


Fig. 2-33: Improved Fireplace.

Heating and Cooling Systems: Residential heating and cooling systems may be the sites of openings through which air infiltration can occur (Figure 2-33). In systems which use air as the transfer medium, the duct work junctions are frequently not tightly sealed. This will permit heated or cooled air to escape from the delivery system before it reaches its destination, or outside air to be drawn unintentionally into the system.

If ducts run through attics or crawlspaces, or outside, then leaks in the ducts mean the furnace is sending its heat directly outdoors instead of into the home. Unfortunately, when insulation covers the duct, it does not block the leaks; it only blocks them from view. To find leaks without stripping insulation, look for moisture marks, discoloration, or dust buildup.

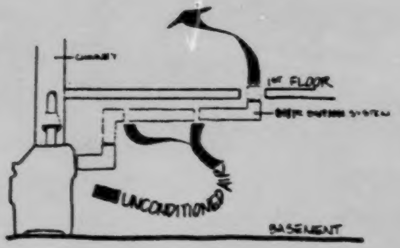


Fig. 2-34: Ducts - Leaky Joints

Whenever such heating systems are not pressurized (i.e., when the fan is not blowing air to its destination), ducts can serve as a chimney. Convection currents, the chimney effect, can cause air to flow upwards through the ducts.

In a multiple story home with large vertical ducts, connected to a furnace in an unconditioned space, a considerable amount of unconditioned air will be drawn into the conditioned space, thus reducing the efficiency of the heating or cooling system and increasing energy requirements. While it is difficult to determine the amount of air infiltration due to this process, one can determine the potential for a chimney effect within the ducts, and the consequent infiltration of unconditioned air into the conditioned spaces. Then one can consider the impact that infiltration through these systems has on the energy requirements.

Caulking: Air leakage in the home accounts for a great deal of energy loss. For an average family of four living in a home of 1728 square feet, Figure 2-35, which is shown on the following page, indicates the seriousness of the problem. Caulking can be the answer to this dilemma.

Where should caulking be done? Caulking should be used wherever two different materials or parts of a house meet. Specifically, a house should be caulked:

a. At joints between window frames and siding.

b. Between window drip caps (tops of windows) and siding.

c. Between window sills and siding.

d. At corners formed by siding.

e. At sill where wood structure meets the foundation.

f. Around outside water faucets, or other special breaks in the outside house surface.

g. Where pipes, wires and ducts penetrate the ceiling below an unheated attic.

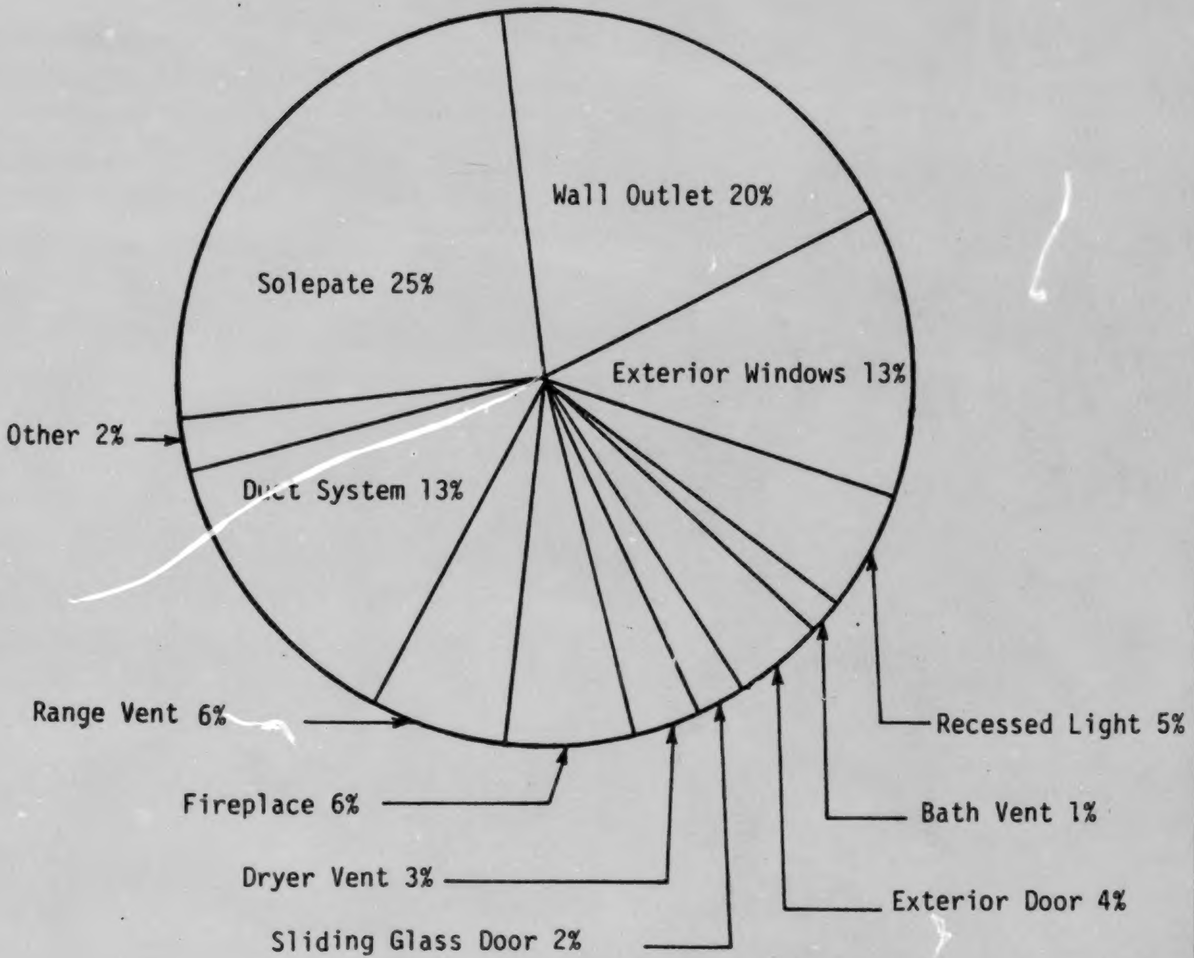
h. Between porches and main body of the house.

i. Where chimney or masonry meets siding.

j. Where storm windows meet the window frame, except for drain holes at window sill.

k. If there is a heated attic, where the wall meets the eave at the gable ends.

AIR LEAKAGE TEST RESULTS FOR AN AVERAGE SIZE HOME
OF 1728 SQ. FT.



SOURCE: Texas Power & Light Company

Figure 2-35.

There are several different types of caulking compounds. Three types that can be considered are:

1. Oil-or resin-based,
2. Latex-, butyl-, or polyvinyl-based,
3. Elastomeric caulks.

All three types will bond to most surfaces such as masonry, wood and metal. The elastomeric caulks are the most expensive, but they are also the most durable.

ENERGY EFFICIENT BUILDINGS

Housing is a major consumer of energy in the United States. Currently it is estimated that some 100 million households are consuming 3 billion barrels of crude oil each year - or 20% of our national energy budget. A number of studies and demonstrations have been directed to the problem of reducing the amount of energy consumed in our housing stock. Most have suggested that a 25-35% reduction in the heating component is possible by making fundamental construction improvements (e.g., upgrading insulation, adding weatherstripping and double glazing) and by being careful in the use of energy (e.g., by setting thermostats at 65° F.). As important as 25-35% savings may be, they can be significantly extended if one is willing to go beyond the "fundamental construction improvements" noted. This requires that the architect fully understand natural energies such as the sun and wind, and be able to respond to them, through passive design, in all phases of planning, design and construction.

Passive design concepts are ideas and concepts which:

- Rely on natural energy, such as that produced by the sun.
- Contain few mechanical parts or complex hardware.
- Require little or no energy themselves, and
- Tend to be low in cost.

Sometimes it is easiest to understand "passive" ideas by contrasting them with "active" design examples. Furnaces, boilers, electric water heaters, heat pumps and air conditioners all fall into the active category; they generally require complex, expensive and energy-consuming equipment. An active approach to solar heating and cooling, for example, may involve a complex solar collector with fans, pumps, storage or heat exchange units and highly sophisticated controls. A more passive approach to solar heating and cooling is a regular window, of the right size and type, with the proper orientation to the sun and wind, and with an insulated operable shutter. On a given day, it can be demonstrated that such a regular window can be as efficient as an active solar collector system!

The primary beneficiaries of these passive approaches are new homes, where the architect is in a position to rethink basic siting, orientation, configuration and layout as well as approaches to the envelope and to what goes into the building. Not all of the passive design concepts, however, are limited to new buildings; many will have applications to existing housing as well.

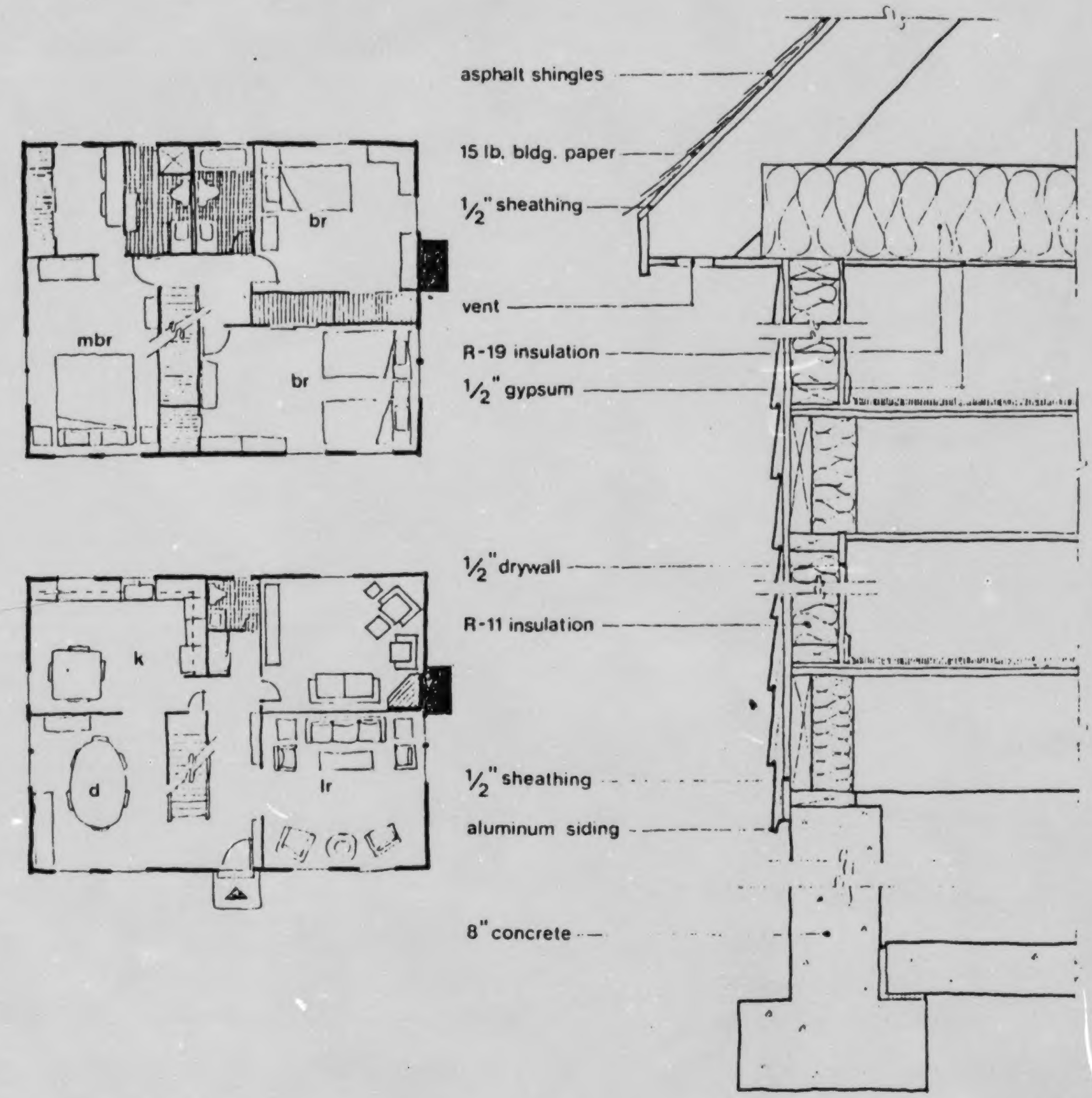
One should, however, make the distinction between two approaches to design: energy conserving design, and energy conscious design. An energy conserving house exhibits standard-practice, energy-conserving construction characteristics such as good insulation, quality weatherstripping, and insulated glass or storm windows and doors. Any good builder who is abreast of current trends can build an energy-conserving house.

The energy conscious house, on the other hand, provides additional energy conservation by incorporating passive design ideas, and by using solar energy through passive systems, in its planning, design, construction and use. Building location, siting, orientation, configuration, layout, construction, mechanical and electrical systems, casework, and interior furnishings are all carefully evaluated in terms of their contribution to energy consumption and conservation. Natural energies are used to their fullest.

In the discussion which follows, the energy conserving design will be highlighted, leaving the energy conscious, or passive, design for a broader treatment in subsequent modules.

An Energy Conserving House

Energy "savings" are always relative. To provide a basis for assessing the impact of a given energy conservation and conscious concept, the standard practice house shown in Figure 2-36 has been developed and analyzed.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mbr
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asphalt shingles
15 lb. bldg. paper
1/2" sheathing
vent
R-19 insulation
1/2" gypsum
1/2" drywall
R-11 insulation
1/2" sheathing
aluminum siding
8" concrete

Figure 2-36: Standard Practice House - Plans and Section.

The plan is that of a rather typical two-story three-bedroom house, with 1600 square feet of living area and a full basement. It is of wood frame construction, with exterior U-values of 0.068 (walls) and 0.055 (roof). It is fully weatherstripped, and includes 342 square feet of window area, double glazed. It is assumed to house a family of two adults and four children, and is located in a region with a climate similar to that found in New York State.

As can be seen from the data presented in Table 2-3, which is shown on the following page, the standard practice house has an annual heat loss of 109,000,000 Btu per year. This is an important point to remember, since all "energy savings" data discussed are over and above the level through conventional construction approaches.

Building Configurations

Overall building configuration impacts residential energy consumption in various ways. The volume of space to be heated and cooled, the amount and disposition of exterior surface areas, room exposure, and basement characteristics all contribute to energy requirements. The major variable is the amount of exposed surface area, which, if minimized, will:

- Reduce heat loss and heat gain by conduction, convection and radiation through the building envelope, and
- Reduce heat loss by infiltration through the envelope. Infiltration is a major component of heat loss, and the amount of this loss is a function of the exposure each room has on the exterior wall of the building. Room exposure, in turn, is a function of configuration.

To explore the impact of building configurations on energy demand, a number of representative variations in ceiling height, location of habitable spaces, number of stories, and geometric form have been developed. Each of these variations is briefly described and their physical characteristics and energy consumption characteristics are summarized and compared to the standard practice house. In each example, the floor area and space complement have been kept the same as the standard practice house.

TABLE 2-3

Physical Description recap:

Floor area	1,600 SF	Exposed surface area: walls	1,824 SF
Volume	12,800 CF	ceilings	800 SF
Perimeter	114 LF	total	2,624 SF

Energy Consumption Characteristics (Winter)[a]:

building element	area (SF)	"U" value	temp diff (°F)	heat loss (BTUH)	% of heat loss
Basement walls	774	4 (SF)	—	3,096	6.1%
Basement floor	800	2 (SF)	—	1,600	3.2%
Exterior walls	1,429	.068	78.6	7,638	15.2%
Windows	342	.504	78.6	13,548	26.9%
Glass doors	35	1.130	78.6	3,109	6.2%
Solid doors	42	.270	78.6	891	1.8%
Infiltration: (CF/hour)	12,200	.018	78.6	17,260	34.3%
Ceiling	800	.055	73.6	3,238	6.3%
Total BTUH:				50,380	
Total BTUs per year:				109,900,000	
Total therms per year:				1,099	
Total therms per year/SF:				0.69	

Energy Consumption Characteristics (Summer)[b]:

building element	area (SF)	"U" value	temp diff (°F)	heat gain (BTUH)	% of heat gain
Basement walls (no heat gain contribution)					
Basement floor (no heat gain contribution)					
Exterior walls	1,429	.068	18.6	1,807	11.0%
Windows:					
Conduction	342	.49	15.0	2,514	15.3%
Radiation—					
North	102	16.66*	—	816	5.0%
South	96	21.39*	—	986	6.0%
East	72	41.25*	—	1,426	8.7%
West	83	41.25*	—	1,643	10.0%
Glass doors	35	1.060	15.0	557	3.4%
Solid doors	42	.420	18.6	328	2.0%
Infiltration: CF/hour	6,100	.018	15.0	1,647	10.0%
Ceiling	800	.055	39.0	1,716	10.4%
Equipment				1,200	7.3%
People				1,800	10.9%
Total sensible heat gain				16,440	100.0%
Latent heat addition (30% of sensible)				4,932	
Total BTUH heat gain:				21,372	

*This figure is the incident radiation adjusted by a venetian blind coefficient (.55). To determine heat gain, this figure is further multiplied by the % of available sunshine during the cooling season (.48).

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[a] Heat-Loss Calculations, Standard Practice House

[b] Heat-Gain Calculations, Standard Practice House

The results are summarized in Tables 2-4, 2-5, 2-6, and Figure 2-37, which are shown in the following pages. Realizing that building configuration is but one of many considerations, the comparisons summarized in Table 2-6, also shown in the following pages, illustrate the importance of some very fundamental decisions - configuration as related to plan and volume. These comparisons only show the impact on heat-loss, and do not reflect any potential benefit or liability due to solar-gain.

TABLE 2-4.

DESCRIPTION OF BUILDING CONFIGURATION OPTIONS

variations:	demonstration:
#1 REDUCTION IN BEDROOM HEIGHT. Since these areas are used on a part-time basis, ceiling height can be reduced, reducing both volume and exterior surface area.	Floor-to-ceiling height of the second floor of the Standard Practice House is reduced from 8'0" to 7'0".
#2 ONE-STORY LONG RECTANGULAR CONFIGURATION. Exterior wall area is reduced by placing all of the program on one floor.	Second floor plan of the Standard Practice House is placed along the 25' side of the first floor plan, creating a long rectangular plan.
#3 ONE-STORY SHORT RECTANGULAR CONFIGURATION. Same as #2, but a more compact plan configuration reduces exterior surface area.	Second floor plan of the Standard Practice House is placed along the 32' side of the first floor plan, creating a more compact arrangement.
#4 CUBE CONFIGURATION. The cube provides the smallest amount of exterior surface area for a given enclosed volume (assuming rectilinear configuration).	The Standard Practice House is redesigned as a cube. Program area is on three floors, each with 7'9-1/2" (instead of 8'0") floor to ceiling heights.
#5 HALF DOME CONFIGURATION. Domes allow the enclosure of space within less exterior surface area than rectilinear configurations.	The program area in the Standard Practice House has been placed in a dome whose equator is at ground level.
#6 3/4 DOME CONFIGURATION. This configuration allows greater use of the least surface area principle.	The program area of the Standard Practice House is placed in a 3/4 dome. Some increase in floor area is needed since area near curving surface not fully usable.
#7 SQUARE FLOOR PLAN. For a one-story solution, a square plan provides the least wall surface area.	The Standard Practice House is redesigned as a 40' x 40' one-story structure. (Figure 2-37).

TABLE 2-4 (continued)

variations:	demonstration:
#8 CIRCULAR FLOOR PLAN. Using a circular plan further reduces wall area to house the required program.	The Standard Practice House is redesigned as a 45'-2" diameter structure. (Figure 2-37).

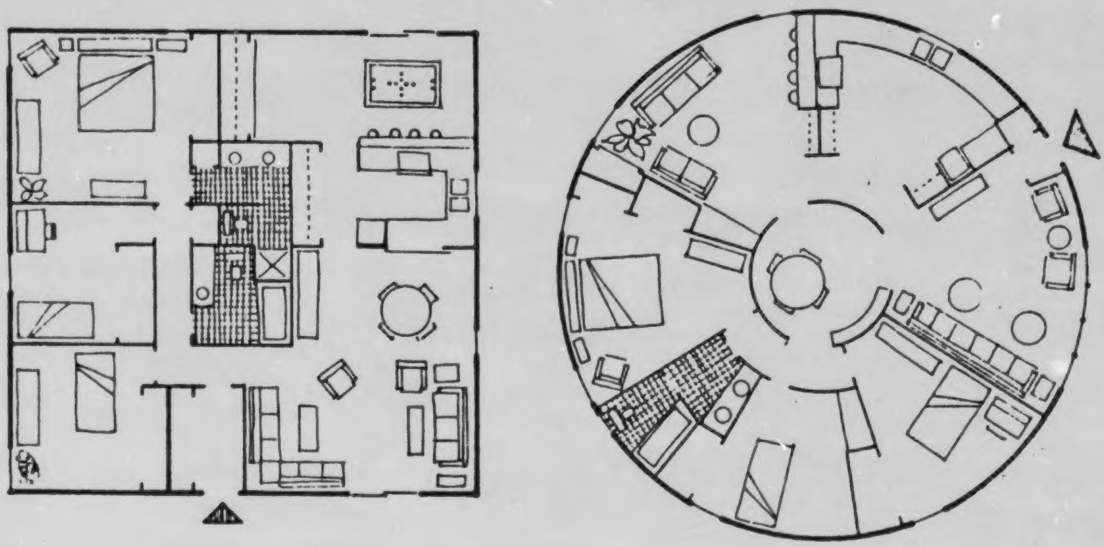

Figure 2-37: Circular and Square Floor Plan Modifications

TABLE 2-5: BUILDING CONFIGURATION OPTIONS - PHYSICAL CHARACTERISTICS

Configuration Options	floor area S.F.	volume C.F.	stories #	perimeter L.F.	exposed walls S.F.	exposed ceilings S F.	total S.F.
Reduction in Bedroom Height	1,600	12,000	2	114	1,710	800	2.510
One-Story Rectangular (long)	1,600	12,800	1	178	1,424	1,600	3.024
One-Story Rectangular (short)	1,600	12,800	1	164	1,312	1,600	2,912
Cube Configuration	1,633	12,800	3	93.3	2.178	544	2.722
Half Dome Configuration	1,623	12,800	2	115	—	—	2,110
¼ Dome Configuration	1,653	12,800	3	87	—	—	2,413
Square Floor Plan	1,600	12,800	1	160	1,280	1.600	2,880
Circular Floor Plan	1,600	12,800	1	142	1.135	1,600	2.735
STANDARD PRACTICE HOUSE	1,600	12,800	2	114	1,824	800	2,624

TABLE 2-6: BUILDING CONFIGURATION OPTIONS - ENERGY CONSUMPTION CHARACTERISTICS

	HEAT-LOSS (BTUH)	Percentage of Total Heat-Loss								PERCENT HEAT-LOSS SAVINGS OVER STANDARD PRACTICE
		Basement walls	Basement floor	Exterior walls	Windows	Glass Doors	Sliding Doors	Infiltration (CF/HR)	Ceiling	
Bedroom Height Reduction	48.750	6.4	3.3	14.4	27.8	6.4	1.8	33.3	6.6	3
Long Rectangular	49,950	9.7	6.4	11.8	22.4	6.1	1.8	28.8	13.0	1
Short Rectangular	48,280	9.5	6.6	11.2	21.2	6.4	1.9	29.8	13.4	4
Cube Configuration	50,130	5.2	2.2	19.0	27.0	6.2	1.8	34.4	4.2	.5
½ Dome Configuration	43,208	7.4	4.8	20.5	31.4	7.2	2.1	26.8	—	14
¾ Dome Configuration	43,166	5.6	2.8	24.3	31.4	7.2	2.1	28.6	—	14
Square Floor Plan	48,000	9.3	6.7	10.9	21.3	6.4	1.9	30.0	13.5	5
Circular Floor Plan	45,660	8.7	7.0	10.1	19.8	6.8	1.9	31.5	14.2	9
Standard Practice House	50,380	6.1	3.2	15.2	26.9	6.2	1.8	34.3	6.3	—

Greenhouses and Atriums

Glass easily transmits shortwave radiation, but is a poor transmitter of longwave radiation. Once the sun's energy has passed through a sheet of glass and has been absorbed by a material behind it, the heat will not be reradiated to the outside. As a consequence, a glassed-in area exposed to the sun acts as a heat trap. There are two special kinds of heat traps that can be incorporated in conventional building designs: greenhouses and atriums.

Greenhouses: Greenhouses attached to residences can perform two key passive design roles; (1) as secondary skins, effectively raising the temperature just outside the building's exterior wall in the winter (and, if plants and shading devices are used, lowering it in the summer), and (2) as passive solar collectors.

The intricacies of greenhouse design, particularly as they are related to plant growth and the environmental controls necessary to sustain growth, lie beyond the scope of this analysis. For passive design purposes, these simple rules-of-thumb may be of value:

- A greenhouse can be constructed as a secondary skin on any facade - but a south-facing greenhouse makes the best passive solar collector.
- The wall between the greenhouse and the residence must be insulated to control heat flow and to prevent overheating.
- Wall surfaces directly exposed to the sun should be dark-colored. Floors should be light-colored if there is danger of their becoming too warm.
- Insulated shutters allow the greenhouse to retain the heat collected after the sun has gone down.
- The distance from the exterior wall of the greenhouse to another object on the landscape (a tree, another building, etc.) should be at least 2-1/2 times the height of the wall.

Given the layout of the standard practice house, a greenhouse has been placed on its west wall (Figure 2-38), instead of the preferred south wall. The west wall in constructed of exposed masonry, painted black, and a rock-storage bed located below the greenhouse floor serves as a storage mass. The energy savings figure shown relates only to the impact of the greenhouse as a secondary skin.

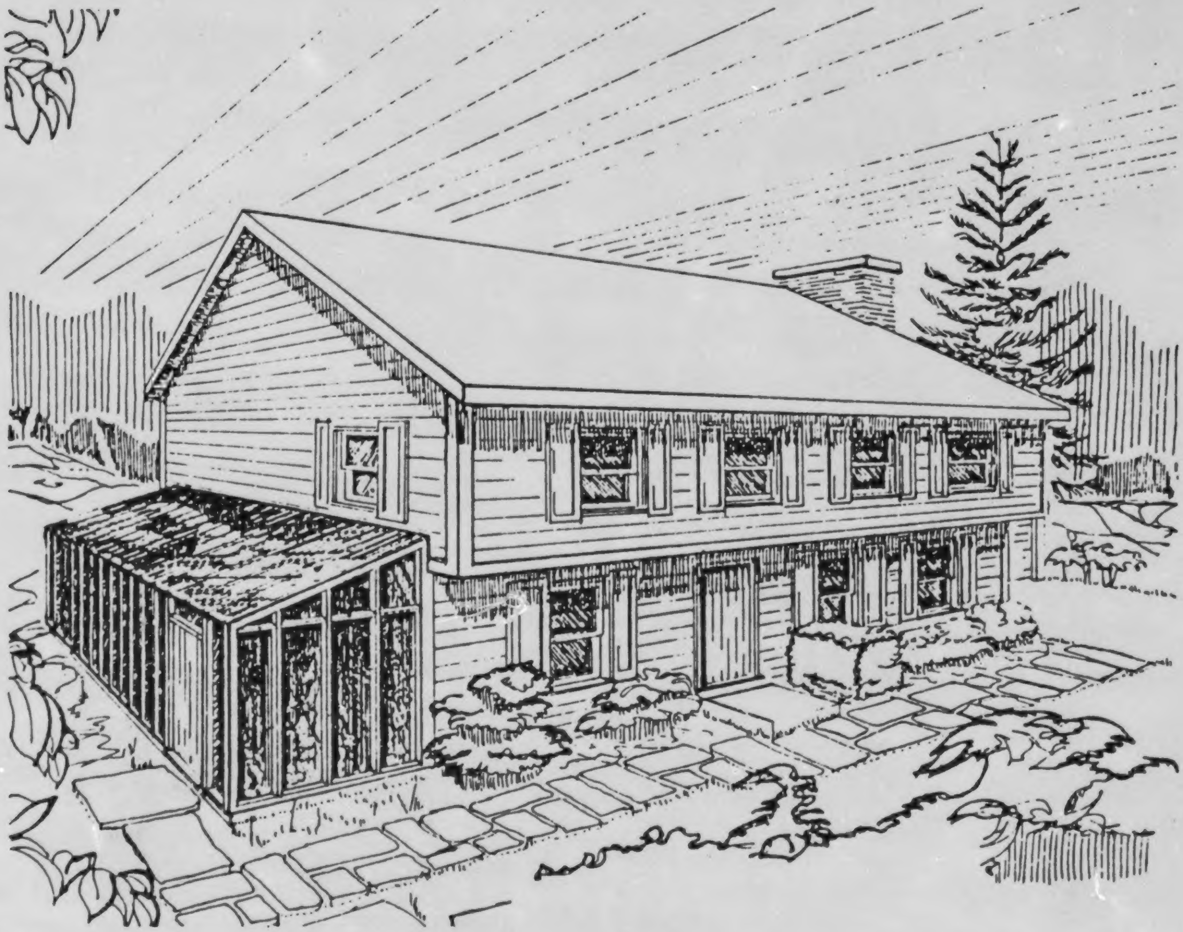

Figure 2-38.
Greenhouse Added to the Standard Practice House.

Heating energy savings. 7.9%
Cooling energy savings. 6.5%

Atriums: Traditionally an atrium is a centrally-located open court within a structure, surrounded by enclosed space and open to the sky. If a major fraction of a building's exterior glass area can be oriented inward to the atrium, energy savings will result; (1) by reducing heat losses through and around windows on the exterior wall of the structure, and (2) by using the atrium as a heat trap (passive solar collector).

Atriums can also serve as positive design features by opening up the floor plans, providing visual privacy from unit to unit and, where desired, allowing higher densities.

To maximize the passive solar collector aspect, it is best if the atrium is covered with a skylight and an insulating shutter (to keep the heat in when the sun goes down, and to provide shading during times of unwanted solar gain).

Two atrium examples are shown in the following pages. The first (Fig. 2-39) adds an unheated, skylight-covered, 14'x14' atrium to the square plan configuration shown earlier under the building configuration analysis. The second (Fig. 2-40) adds a 16' diameter atrium to a circular plan house. In both cases, total perimeter has been increased to assure 1600 square feet of program area, and there is no basement under the atrium. On a cold winter's day (0° F), the inside temperature of the atrium is increased significantly. (It is calculated to be 31.5° F in the first case and 36.7° F in the second). Table 2-7 summarizes the impacts of these atriums on the heat-loss patterns of the two example houses.

As in the case of the greenhouse demonstration, the atrium examples only indicate the impact of the atrium on reducing the heat loss through the envelope; the amount of solar energy which can be collected and stored in all of the examples depends on location, insolation, characteristics, and specific design features (heat-storage system, insulation used, design of the residence itself).

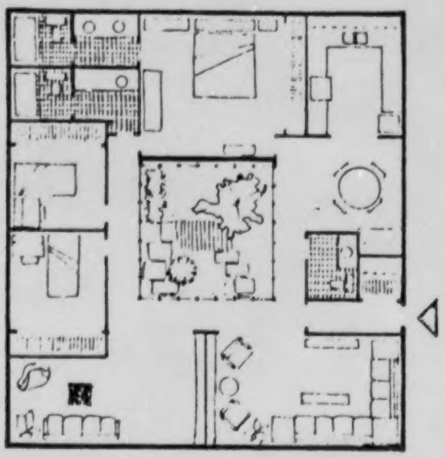

Fig. 2-39: Square Plan with an Atrium
Energy Savings. . . 21.5%

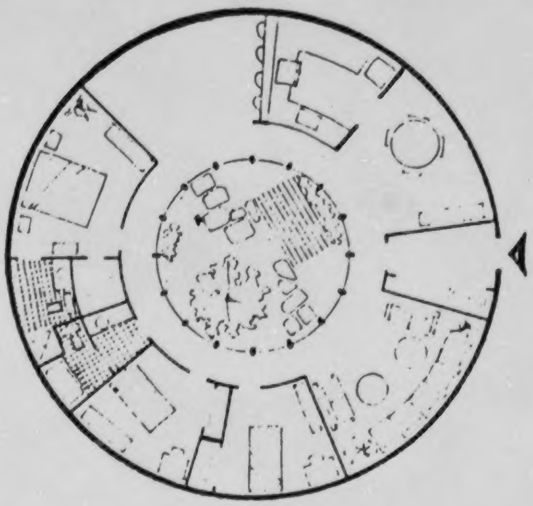

Fig. 2-40 Circular Plan With an Atrium
Energy Savings. . . 27.6%

TABLE 2-7.
ATRIUM EXAMPLES: HEATING ENERGY CONSUMPTION CHARACTERISTICS

	Standard Practice House	Square Plan with Atrium	Circular Plan with Atrium
	percentage distribution of heat loss		
Basement Walls	6.1	16.0	15.4
Basement Floor	3.2	8.1	8.8
Exterior Walls	15.2	17.8	17.0
Interior Walls (Atrium)	—	0.6	0.5
Windows and Glass Doors	33.1	17.1	14.4
Solid Doors	1.8	2.2	2.4
Infiltration (CF/hour)	34.3	21.8	23.7
Ceiling	6.3	16.4	17.8

Note: The perimeter of the Standard Practice House of 114 LF has been increased to 170 LF in the square configuration and 151 LF in the circular configuration. The total exterior surface area has also been increased from 2,624 SF in the Standard Practice House to 2,967 in the square, and 2,806 SF in the circular configuration.

Earth Berming

Appropriately used, the earth we build in can be an effective passive design tool. Placed between a building and the outside elements, earth slows the heat transfer from one to the other, reduces the temperature difference between exterior and interior; and at the same time, it protects the building from cold winds and the direct rays of the sun.

While earth does provide some degree of thermal resistance, it is not, in principle, a good insulator. A layer of insulation, therefore, must be located between the building and the earth which surrounds it, or the earth will act as a heat sink - always drawing heat away from the interior of the building. (Nearby rocks and water in the soil will increase this drawing effect).

Bedrooms Below Grade: Perhaps the simplest approach to using earth in homes where basements will, or can, be added is to consider placing bedrooms on the lower, partially below-grade, floor. The notion is not a novel one, but people often resist the idea of being below - or partially below - the ground level. Yet bedrooms and associated bath, dressing and storage spaces are generally used in the evening hours and, as will be seen, the energy impact can be dramatic.

For the analysis of bedrooms below grade (Figure 2-41), the standard practice house is modified to place the second floor activities on the lower level.

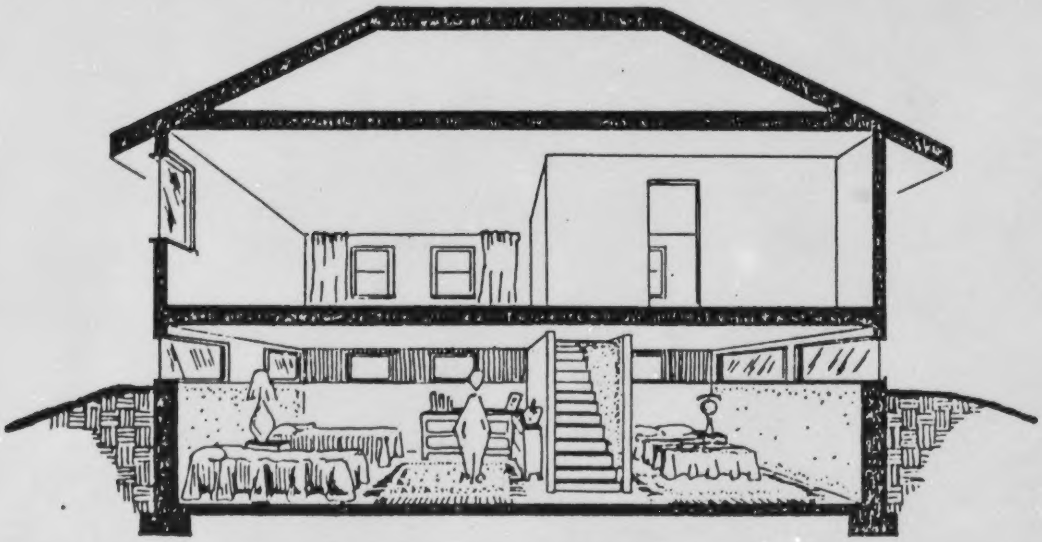

Figure 2-41: Bedrooms Below Grade

Energy Savings 23.1%

Basement height has been increased to 8'0" to allow a 7'6" clear height and a 6" plenum for ducts and pipes. A 2'0" strip of clerestory windows replaces the window area designed into the standard practice house, and the remaining 6'0" are entirely below grade.

Berming to Window Sills: In areas where basement construction is not used, or where soil conditions or other problems preclude it, earth can be bermed against the side of the structure to reduce heat loss and heat gain through the exterior wall. At minimum, earth can be bermed up to the height of conventional window sills (see Figures 2-42 and 2-43, which appear in the following pages). This does not interfere with views or ventilation, and it has a minimal visual impact on the appearance of the house.

Berming to Roof Eave: Where clerestory windows can be used, berming the earth nearly to the roof eaves produces more dramatic energy savings. In the example shown (Figure 2-44, which appears in the following pages), the square floor plan presented in the discussion of the building configurations has been modified to include clerestory windows, and earth has been bermed up to the 6'0" sills of these windows. 35 linear feet of doors and floor-to-ceiling windows have been left to provide access and some exterior views.

Energy Consumption Impact: Table 2-8, which appears in the following pages, summarizes the energy consumption impact of the earth berming examples shown. Earth berming requires some care. The slope of the earth should not exceed 45°; a steeper slope will present problems in maintaining plantings as well as maintaining the necessary thermal benefits of the earth.

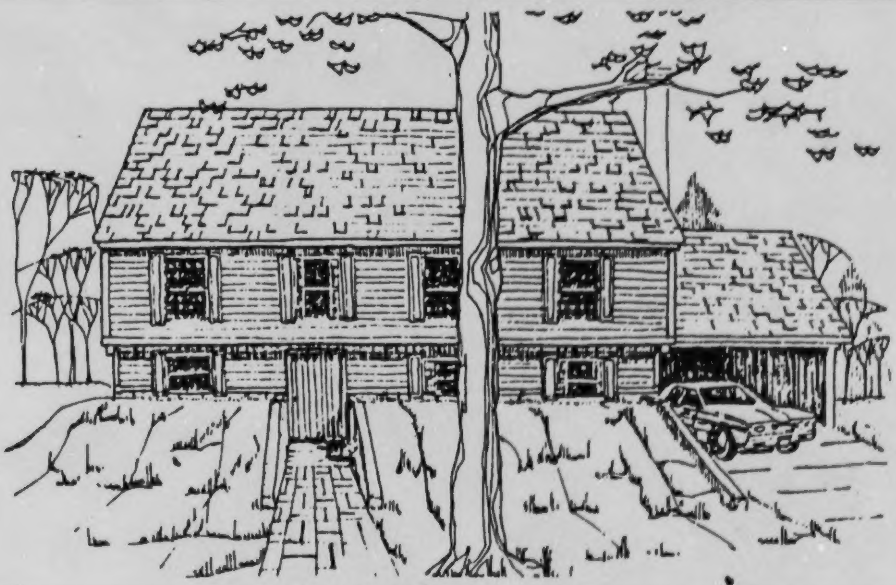

Figure 2-42.
Earth Berming to Window Sills: Standard Practice Energy Savings 6.6%

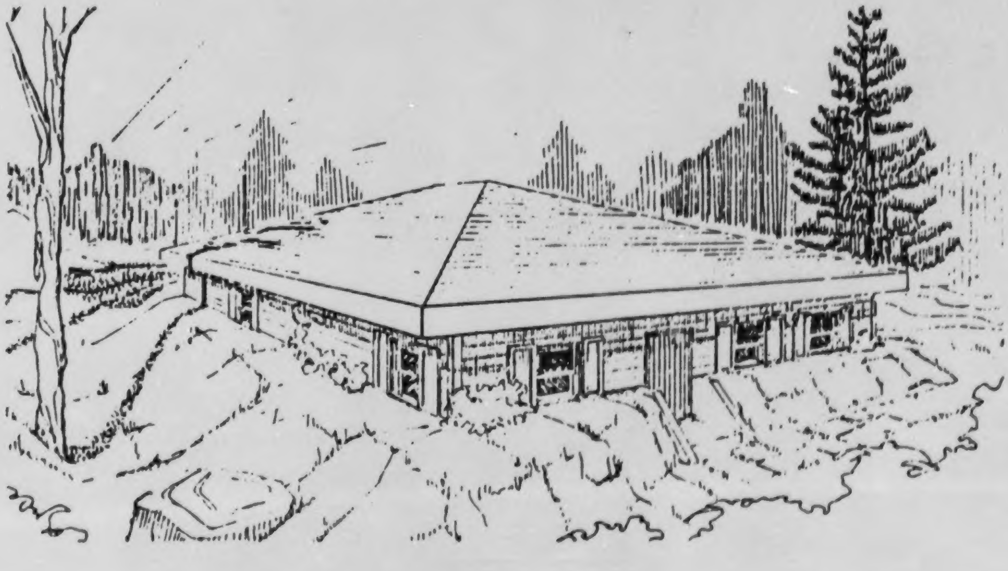

Figure 2-43.
Earth Berming to Window Sills
Square Plan House Energy Savings 13.1%

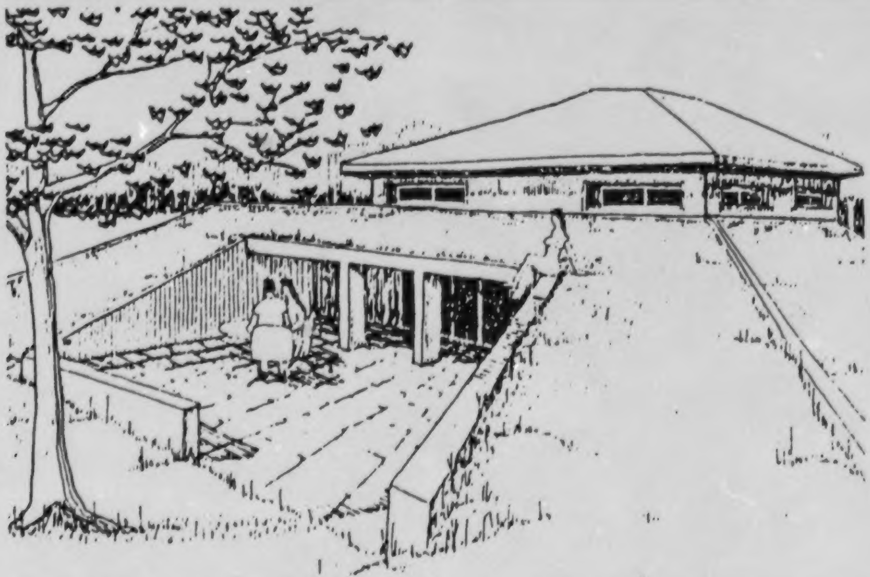

Figure 2-44.

Earth Berming to the Roof Eave:
Square Plan House Energy Savings. 31.7%

TABLE 2-8.
ENERGY CONSUMPTION IMPACT OF EARGH BERMING

	Percentage distribution of heat-loss			
	Standard Practice House	Standard Practice House—Window-sill Berming	Square Plan Window-sill Berming	Square Plan Roof Eave Berming
Basement Walls	6.1	6.8	10.2	13.0
Basement Floors	3.2	3.4	7.3	9.3
Bermed Wall	—	1.5	2.5	2.7
Exposed Wall	15.2	12.7	6.5	4.2
Windows	26.9	26.8	20.0	16.6
Glass Doors	6.2	6.6	7.1	9.0
Solid Doors	1.8	1.9	2.0	1.3
Infiltration	34.3	33.4	29.6	25.1
Ceiling	6.3	6.9	14.8	18.8
ENERGY SAVINGS OVER STANDARD PRACTICE HOUSE	—	6.6%	13.1%	31.7%

Solar Collectors on Earth Berms: Earth berming offers another passive design possibility: integration of flat-plate solar collectors with the berms. The sloped surface of the berm provides support for the collector, while the area below the collector can serve as thermal storage with ducting directly to the interior of the house (Figure 2-45). Drawing outside cool air through the storage component allows use as a cooling system as well.

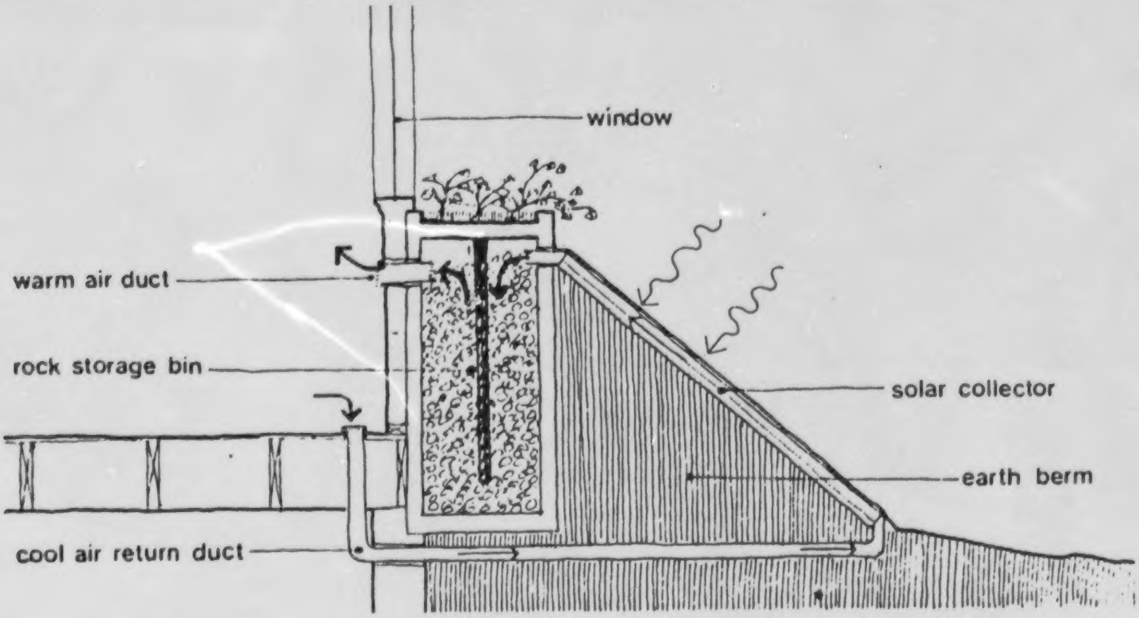

Figure 2-45.
Solar Collector Integrated with an Earth Berm

Underground Houses

A logical extension of earth berming is to place the residence completely, or nearly completely, underground. While there are a number of design approaches to underground buildings that could be considered here, the subject is beyond the scope of the present subject area. Underground structures are now the subject of a great deal of research, e. g., reference 6.

Basic Precepts: Here are some basic precepts to keep in mind when working with earth as a passive design material or underground shelter:

1. Gentle south slopes are ideal for underground structures. You can easily build into the hill, have south sunlight and positive drainage.

2. Avoid low-lying depressions. Heavy, cold air drains into them; frost and dampness are more likely in these areas.

3. Make sure that surrounding construction (parking lots, septic systems, etc.) do not drain into the site.

4. Identify ground water levels (including seasonal variations) before making decisions on placement and depth.

5. Adequate soil percolation is essential, particularly for sunken courtyards and atriums. If there are problems, consider the installation of overflow drains.

6. Any structural system can be used, provided it is designed to applicable loading conditions. General rules are 150 PSF for roofs with grass cover, and 400 PSF for roofs when the earth cover is to support small trees. Add snow, water and pedestrian loads.

7. Wall design is generally the same as conventional basement wall or other below-grade construction.

8. Place insulation on the outside of the below-ground building structure; this allows the structure to serve as a heat-storage mass. Insulation can be reduced in thickness as the depth below grade increases. The best current insulating material for this application is styrofoam with its closed cell construction.

9. Butyl sheets provide both waterproofing and a vapor barrier.

10. For earth berming against existing exterior walls, a cememt plaster finish applied to metal lath and a vapor barrier on the existing wall will do the job. This detail also discourages roots, insects and rodents from getting into the wall.

11. Avoid curbs or parapets to retain earth roof covering. Freezing and thawing action will tend to crack these elements.

12. To control interior dampness, dry the air through circulation and/or dehumidification.

13. Earth pipes can be used to provide natural cooling. Air taken from the outside during warm weather can be cooled by passing it through long pipes buried in the berm or below grade. The same piping can provide some degree of preheating fresh outside air during cold weather.

14. Examine local codes, especially in relation to fire exits and ventilation.

15. Lighting usage should be thought out carefully. It will affect both comfort and energy use more critically in an underground house.

An Energy Conscious House

It is feasible to include many combinations of passive design concepts in a single residential building. When this is done, however, the percentage of energy savings given for each individual concept cannot be simply added together to derive a cumulative energy saving. To provide some indication of this cumulative energy-saving potential, an energy conscious house (Figures 2-46, 2-47 and 2-48 on the following pages) has been developed. The energy conscious house includes the same floor area and complement of spaces as the earlier standard practice house. The passive design concepts included in it are readily implementable. They require no changes in lifestyle; they can be accomplished within today's construction technology, and they involve no active solar technology. They include:

- One-story building configuration
- Earth berming to the window sills
- Reflective surfaces within the envelope
- Flexible walls

- Atrium/greenhouse
- Individual hot water system
- Entry locks
- Closets located against exterior walls
- Individual heating zones with clock thermostats
- Window sash and insulated glass
- Window shutters.

The energy conscious house totals 1646 square feet of floor area plus 182 square feet of unheated atrium space. Its finished volume is 13,494 cubic feet, or 694 cubic feet larger than the standard practice house. As indicated in the background data (Table 2-9, which is shown in the following pages), it provides a 34.2% saving in heating energy, and a 23.1% saving in cooling energy over the standard practice house.

In reviewing the data for the energy conscious house, these points should be stressed:

- The savings are percentage figures showing the impact of the passive design concept on the standard practice house.
- The energy conscious house meets, or exceeds, all space and program requirements incorporated into the standard practice house.
- The energy conscious house uses only a fraction of the passive design ideas that are available.
- Indoor temperature for all comparisons is 70° F. Additional energy may be conserved by turning down the thermostats in the wintertime.

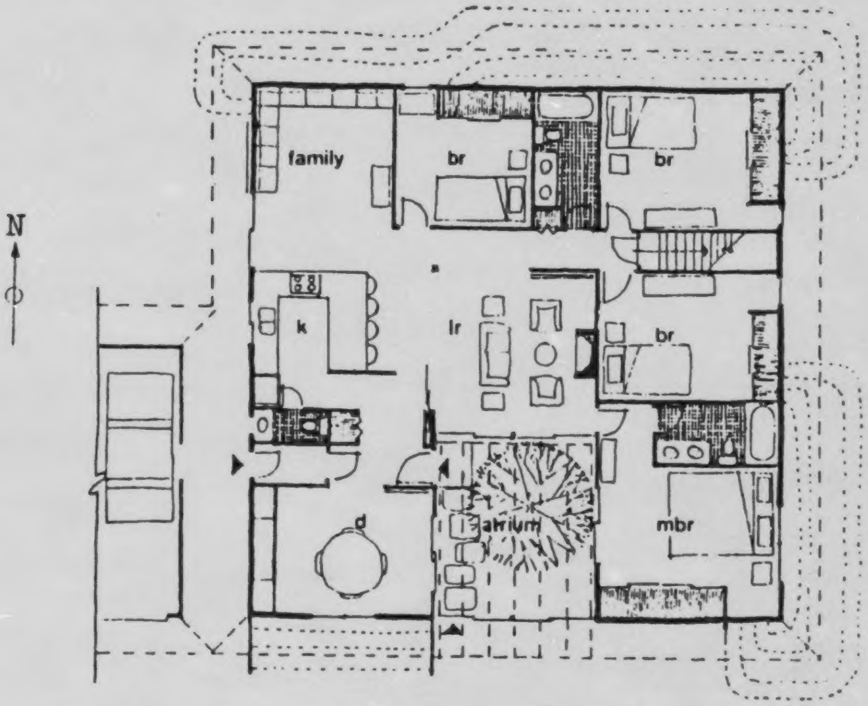
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Figure 2-46. Energy Conscious House Plan.

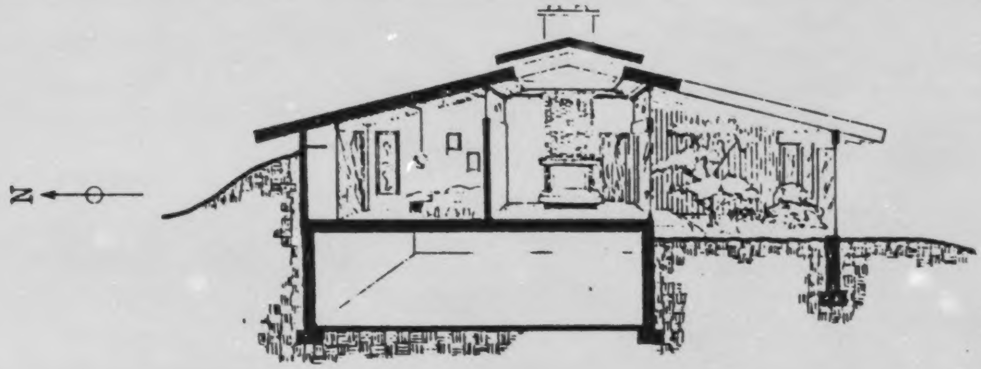

Figure 2-47. Energy Conscious House: Section

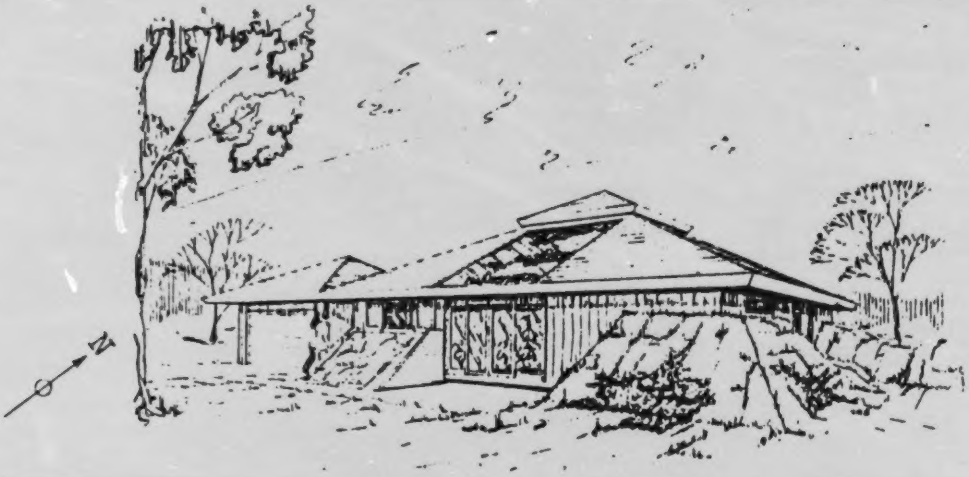

Figure 2-48: Energy Conscious House: Perspective

TABLE 2-9.
ENERGY CONSCIOUS HOUSE: ENERGY DATA

BACKGROUND DATA

- Exterior walls are constructed of 2x4 and 2x6 (in bermed areas) members.
- Floors are framed with 2x10 members.
- Roof is framed with 2x12 members; has a 2:12 slope and a 3'-0" overhang with adjustable louvers on all sides.
- Atrium is covered with a skylight and a canvas shade to reduce heat gain when this is desired.
- Exterior doors are solid wood core with storm doors; windows are wood sash with storms (slightly less window area than Standard Practice House).
- House is zoned into three sectors. Use pattern is as shown under 'heating energy' below. Temperature mained at 70°F during 'occupied' times and 55°F at other times.
- House includes operable shutters (U value: .115) which are open from 8am to 4pm in the wintertime. Summer schedule for shutters on east windows is 1pm to 4pm; shutters on south windows, 7am to 9am and 3pm to 5pm; west windows, 8am to 11am; north windows, 8am to 7pm.

TABLE 2-9 (continued)

HEATING ENERGY zone	Weekday Heat Loss hours occupied	Weekday Heat Loss heat loss (BTU/day)	Weekend Heat Loss hours occupied	Weekend Heat Loss heat loss (BTU/day)
1. Kitchen, family, half-bath, circulation	16	142,660	16	139,560
2. Living and dining areas	10	100,840	16	114,230
3. All bedrooms	12	169,250	12	168,760
4. Basement loss		234,400		234,400
Total daily heat loss		647,150		656,950
Average daily heat loss				649,950

The consumption pattern for the Energy Conscious House includes the impact of heat gain in the winter—an important feature of the design. To compare it with the Standard Practice House it is necessary to adjust the total heat loss of the latter for winter heat gain:

heat gain on January 21	window area (SF)	heat gain (BTU/SF/day)	heat gain (BTU/day)
North wall	102	118	12,036
South wall	96	1,630	156,480
East wall	72	508	36,580
West wall	83	508	42,160
Total heat gain on January 21			247,256

Subtracting this heat gain (247,260 BTU/day) from the total for the Standard Practice House (1,209,120) leaves a net loss of 961,860 BTU/day. Comparing this to the figures for the Energy Conscious House above:

HEATING ENERGY SAVINGS 34.2%

COOLING ENERGY Heat gain on June 21:	heat gain (BTU/day)
Gain through conduction, radiation, bathroom infiltration	80,910
Gain through the roof	23,860
Gain through infiltration (ventilation)	49,440
Gain from kitchen and other equipment	19,200
Gain from people (6 occupants)	28,800
Total sensible heat gain—June 21	202,210
Latent heat addition (30% of sensible gain)	60,660
Total daily heat gain—June 21	262,870

The total daily heat gain for the Standard Practice House on June 21 is 341,920 BTU. Comparing this to the figures for the Energy Conscious House:

COOLING ENERGY SAVINGS 23.1%

HOT WATER HEATING ENERGY

heater	operating characteristics
#1 serves master bedroom bath/shower	7.5 gallon capacity individual heater operated on demand (used 2-4 times a day)
#2 serves the second bath/shower	(same as #1)
#3 serves dishwasher/washing machine	15 gallon capacity individual heater operated on demand (used once a day)
#4 serves sinks and lavatories	10 gallon capacity, used continuously (supplies 100 gallons of 150°F water daily)

The total heating energy required for heating hot water in the Energy Conscious House is 134,200 BTU/day. Comparing this to the 210,000 BTU/day required in the Standard Practice House:

HOT WATER HEATING ENERGY SAVINGS 36.2%

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ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

HVAC AND ENERGY CONSERVATION

STUDENT MATERIAL

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

HVAC AND ENERGY CONSERVATION

INTRODUCTION

As early as 1500 A. D., Leonardo de Vinci built a water-driven fan to ventilate a suite of rooms for the wife of his patron. This was possibly the first attempt to provide an automatic way of changing the condition of the air in an enclosed space. Another such device was the punka, a large fan extended from the ceiling, which originated in India many years ago. It was operated manually by pulling a rope; some of the later models were machine-operated. Although these may appear ludicrous today, they represent the progress in our attempts to control the surrounding air.

Before 1922, conditioned air was used to produce items such as candy, gum, cheese, and matches; during 1922, the first comfort installation was made in a theater. This 1922 installation consisted of a central station spray-type, down-draft, bypass system. Since that time, almost every major type of building has been air conditioned, from giant skyscrapers to small homes. The discovery of the principles of air conditioning is one of the most important events in the Twentieth Century. Human beings work harder and more efficiently, play longer, and enjoy more leisure in comfort because of air conditioning.

Since the first scientific air-conditioning system was used in a printing house over half a century ago, the scientific achievement and uses of air-conditioning principles have been outstanding. For example: Military centers which can track and intercept hostile missiles are able to operate around-the-clock only because the air is at a controlled temperature; without air conditioning, the computers quickly cease to operate because of the intense, self-generated heat. Atomic submarines can remain submerged almost indefinitely due, in part, to air conditioning. Modern medicines, such as the Salk and Sabin vaccines, are prepared in a scientifically controlled atmosphere. The exploration of space is aided by air conditioning. The uses of air conditioning show that when new products are made, or when new discoveries take place, and certainly in the exploration of space, air-conditioning plays a key role.

The basic concepts of air conditioning are not understood or even thought about by countless millions who enjoy the comfort produced by it. Yet, air conditioning is a readily accepted part of modern life. Because of this, air conditioning requires a definition: Air conditioning is defined as a process which heats, cools, cleans, and circulates air, as well as controlling the moisture content of air. Ideally, air conditioning does all of the tasks at the same time and on a year-round basis. Thus, air conditioning makes it possible to change the condition of the air in an enclosed area. Since most people spend a large portion of their lives in enclosed areas, air conditioning is actually more important and produces more benefits than realized by a majority of people.

Table 3-1 shows that 15.7% of the total U. S. energy budget is devoted to heating (space and water) and cooling (air conditioning and refrigeration).

ENERGY USE: Percent of Total U. S. Energy Use in Residential Sector

ENERGY RESOURCE		ENERGY USE		
Wood	Nil	Space Heating	11.0%	15.7%
Coal	Nil	Water Heating	2.9%	
Natural Gas	7.3%	Air Conditioning	0.7%	
Electricity	7.5%	Refrigeration	1.1%	
Oil	4.4%	Cooking	1.1%	
Total	19.2%	Lighting	0.7%	
		Other (Small Appliances)	1.7%	
		Total	19.2%	

Table 3-1.

When searching for ways to simplify lifestyles, there is no better place to start than with air conditioning.

The fundamentals of heating and cooling addresses the design, installation and proper use of space heating and cooling systems for the home, and touches on energy saving tips for the consumer. Once a basic house is designed to include amounts of insulation, types and sizes of windows, size and shape of the house, orientation, etc., the homeowner must then determine the heat loss and heat gain requirements of a building, so that a balance between the two can be obtained by properly adding air conditioning. This is one of the most important considerations in examining energy use and energy abuse in a home.

The first step in reducing energy consumption and fuel bills is understanding some of the basic principles of heating and cooling.

BASIC PRINCIPLES OF AIR CONDITIONING

A study of "body comfort" shows how the body is able to remain comfortable if the air temperature, relative humidity (moisture), and air movement are within favorable limits. Since there are few days in the year during which all three conditions are ideal, it is necessary for human beings to adjust to maintain even a minimum of comfort. In the absence of air conditioning, humans must adjust their manner of dress in an attempt to balance the extremes of weather conditions. Although a practical method of maintaining air comfort conditions out-of-doors has not yet been achieved, the problems of conditioning indoor air has been solved. Indoor air can be too cold, too hot, too wet, too dry, too drafty, and too still. These conditions are changed by treating the air. Cold air is heated, hot air is cooled, moisture is added to dry air, moisture is removed from damp air, and fans are used to create and maintain an adequate air movement. Each of these air treatments is accomplished in the air-conditioning air cycle.

First, remember that the total heating or cooling bill depends upon two factors:

1. The efficiency of a furnace, air conditioner, or other appliance;
2. The amount of work it is asked to do.

Efficiency is a measure of how much energy is actually used in doing a particular job; 100% efficiency means no wasted energy, while 50% means half is wasted. A fact often ignored is the actual amount of work required to do the job. A poorly insulated house requires far more energy to heat and cool than does a well insulated house. Sealing air leaks, adding insulation, and doing other simple jobs can do far more to reduce fuel bills than buying the most sophisticated, expensive, high-efficiency furnace or cooler on the market. Many homes today have fully controlled temperatures year around. In winter, the home is heated by a furnace; in summer, it is cooled by an air conditioner. The inside temperature is regulated by a thermostat. Although there are many different types, brands, and models of heating and cooling equipment, the basic purpose is the same - to keep the occupants comfortable - neither too hot nor too cold. Using efficient equipment is one way to cut down energy consumption, and adding insulation is another.

Energy Units

Energy units refers to something bought in measured amounts. Different kinds of energy come in different forms and are measured in different units. For example, one buys natural gas by the cubic foot, gasoline and fuel by the gallon, and coal by the ton. But energy consumption does not take place instantly - time is required to use up the fuel.

Electrical Energy Units: Measuring electrical energy is sometimes confusing, because it cannot be measured in a unit or quantity that one can see. Electrical appliances are rated in watts, which indicate the amount of power consumed, but power and energy are not the same. The electric meter records energy consumption in watt-hours or kilowatt-hours (KWH). (The prefix kilo- means 1000, so a kilowatt is 1000 watts). In other words, energy is equal to the product of power and time. If a 100-watt light bulb burns for one hour, 100 watt-hours of electrical energy are consumed ($E = P \times T$). If the same bulb burns for two hours, it would have consumed 200 watt-hours, or 0.2 kilowatt-hours will be consumed. If the electric power company charges 5¢ per kilowatt-hour, then 0.2 KWH would cost 0.2x5 = 1¢.

Heating Energy Units: The British thermal unit (Btu) is the basic unit used in measuring heat energy, and the energy capacity of heating equipment is measured with this unit. For example, a moderate-sized home in a northern state might have a furnace rated at 100,000 Btu. The furnace is rated on the basis of how much heat it can deliver to the house. As these figures indicate, one Btu represents a fairly small amount of heat energy. Technically speaking, a Btu is the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. However, this unit is easier to visualize by thinking of a Btu as being about equal to the heat delivered in one hour by the flame of one candle on a birthday cake. The one hour refers to the heat output of the candle, which is actually one Btu per hour. Home heating requirements are also figured in Btu.

The heat load is the amount of heat that escapes from a structure through - walls, windows, doors, ceilings, floors, etc. If a house has a 100,000 Btu heat load (figured on the coldest expected temperature), it will require a furnace with at least 100,000 Btu capacity to heat the home. Electrical heating equipment is sometimes sized in watts instead of Btu, particularly with baseboard heaters and space heaters. Since the Btu and the watt-hour are both units of heat energy, a simple conversion factor can be used to relate them. One watt-hour is roughly 3.4 Btu; similarly, one kilowatt-hour is about 3400 Btu. To convert watts to Btu, simply multiply the number of watts by 3.4. Alternatively, to convert Btu to watts, divide the Btu rating by 3.4.

Cooling Energy Units: When air-conditioning a home, the terms heat gain or cooling load are used to specify the amount of heat that must be removed from the home. The British thermal unit (Btu) is the basic unit used in measuring heat energy, and the energy capacity of cooling equipment is measured with this unit. For example, a moderate-sized home in a northern state might have a cooling unit rated at 36,000 Btu; i.e., the cooling unit is rated by how much heat it can remove from the house. A home having a summer heat gain of 36,000 Btu (figured on the hottest typical day) would require an air conditioner rated at 36,000 Btu. This cooling capacity is easily accomplished with a moderately sized central unit, or several smaller window-mounted units totalling 36,000 Btu. Larger air conditioners are normally measured in tons of refrigeration, which has nothing to do with the air conditioner's actual weight. In this system, one ton of cooling capacity corresponds to 12,000 Btu. Thus, a 36,000 Btu air conditioner would also be rated as a 3-ton air conditioner. The ton unit came about in the early "icebox" days of refrigeration, because it represented the amount of heat energy required to melt one ton of ice in twenty-four hours.

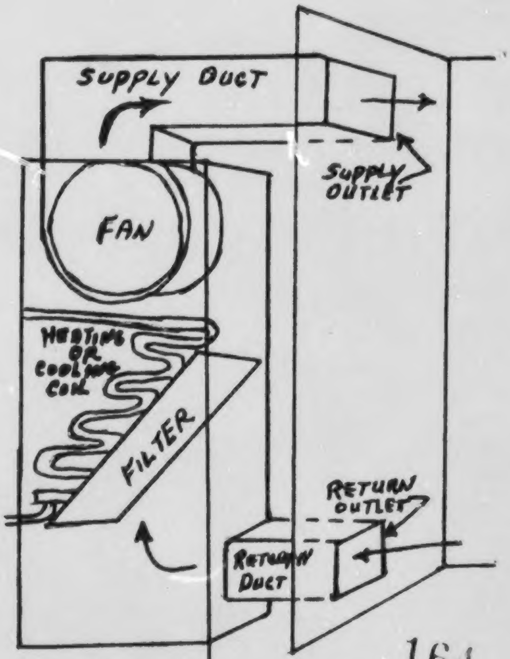
Energy Efficiency Ratio: The energy efficiency ratio (EER) is a handy way to compare the efficiencies of various air conditioners. The EER is equal to the Btu rating divided by the input watts. Air coolers do not produce heat directly; instead, they merely transfer, or pump, heat energy from one place to another. In a refrigerator, for instance, the motor pumps Freon gas through coils located both inside and outside the refrigerator. One coil absorbs and removes heat energy from the inside, thus making it cold, while the second coil dissipates the heat into the outside air circulating over its fins.

The advantage is that less energy is required to pump heat than to generate it, as in a heater. This is proven by the fact that typical conditioners with an EER between 5 and 10, and that a typical air conditioner is capable of removing about 25 times as much heat energy from the home as the unit itself consumes in electrical energy.

The EER for an air conditioner is determined under prescribed test conditions of temperature and humidity, and this is done so that one can easily compare the performance of all cooling units. But it must be pointed out that outside temperature will vary while the unit is actually in operation, thus influencing the efficiency with which an air conditioner can pump heat out of the house. The official EER rating reflects a typical summer operating condition; however, one can expect that an air conditioner will use more electrical energy on extremely hot days and less on cooler days.

The Air Conditioning Cycle

The cycle described here is typical in the sense that it contains the basic air-conditioning system parts that are required to supply and remove air from a room. During this process, the air is conditioned as needed, as illustrated in Figure 3-1. The room or the space to be conditioned is one of the most



THE AIR CYCLE

important parts of the air cycle. The dictionary states that a room is an enclosed space set apart by partitions. If an enclosed space does not exist, then it is impossible to complete the air cycle. This is due to the fact that the conditioned air from the supply outlet simply flows into the atmosphere. In fact, the material and the quality of workmanship used to enclose the space are also important, since these factors help to control the loss of heat or cold that is confined in the enclosed area.

The air cycle begins when the fan forces air into ductwork leading to openings in the room. These openings are called outlets or terminals. The air is directed from the ductwork through these outlets and into the room, where the air either heats or cools the room as needed. Dust particles in the room enter the air stream and are carried along with it. The air then flows from the room through a second outlet or return outlet. Dust particles are removed from the air by a filter installed in the return ductwork. After the air is cleaned, it is either heated or cooled, depending on the requirements of the room. If cooling is required, the air is passed over the surface of a cooling coil. If heat is required, the air is passed through a combustion chamber or over the surface of a heating coil. Finally, the air is returned to the fan and the cycle is completed.

Design Temperature Differences: In terms of room temperature, 68° F is just a bit on the chilly side, while 77° F is just a bit on the warm side. The temperature difference is the difference between the inside and outside temperature of a building. As the temperature difference increases, the heat load or cooling load also increases. The inside temperature in a home is regulated by using heating and cooling equipment. However, the inside temperature also affects the temperature difference between the inside and outside of the house. Thus the setting of the thermostat changes the heating and cooling load of the home.

A point to remember is that the heating and cooling loads for a home will not be the same, because different temperatures are involved. A house with a heat load of 80,000 Btu will not have a cooling load of 80,000 Btu, except possibly in some southern states. In a typical northern state, the house might have an 80,000 Btu heat load and a 36,000 Btu cooling load. The difference in heating and cooling loads results because the loads are figured using different design temperatures and inside temperatures, and also because they include solar heating effects due to sunlight.

The design temperatures vary according to location in the nation, and the heating and cooling loads in areas can be found for almost any structure by using charts and tables designed for that very purpose. The heating and cooling loads are also affected by what is inside the building. Appliances such as stoves, toasters, irons, ovens, washers, and dryers produce heat. Lamps, in addition to giving light, also contribute heat. People, whether sitting or actively moving about, also generate varying amounts of body heat. In winter, this extra heat is welcomed because it lowers the heating load, but in summer, this extra heat places an added burden on the air-conditioning system that must remove it.

Design Temperature Differences for Heating: Design temperatures vary according to location in the nation, and the winter design temperature tells how cold it will usually get in an area. The design temperatures will determine the heat load of the home and, therefore, the size of the required heating unit. For example, the winter design temperature in Milwaukee, Wisconsin is -17° F. The temperature difference for a home in Milwaukee with its thermostat set at 63° F would then be 80° F. Similarly, the winter design temperature in Jacksonville, Florida is 33° F, so for the same thermostat setting, the Milwaukee home would require a much larger heating unit than an identical home in Jacksonville. As the temperature difference increases, the heat load also increases. Consequently, more fuel will be required to heat a house when the difference between the inside and outside temperature is 70° F than when the temperature difference is only 30° F. Lowering the thermostat in the winter lowers the heat load of the home, meaning that less energy is consumed by the furnace in maintaining the home at the desired temperature.

The Winter Air-Conditioning Cycle: During winter operation, the air-conditioning cycle adds heat to the air. The return air from the room is passed over the surface of a heating coil or over the surface of a combustion chamber. The air is heated to the required temperature and then delivered to the room through the supply duct. The air loses its heat to the room and passes through the return duct to the coil or chamber.

The cycle is repeated as long as the heated air is required. If the room air is too dry, moisture can be added by installing shallow pans in the bonnet above the combustion chamber or in the ductwork after the coil. The pans are automatically filled with water to a preset level. Thus, moisture is added to the air by the process of evaporation as the air passes over the pans.

Design Temperature Differences for Cooling: Summer design temperatures also vary according to location. The summer design temperature tells how hot it is expected to get in the summer. In Milwaukee, Wisconsin, for example, the summer design temperature is 95° F, while in Jacksonville, Florida, it is 104° F. The design temperatures will determine the cooling load of the home, and therefore the cooling units used in these areas must be sized according to the summer design temperatures. Raising the inside temperature of the home during the summer means that the cooling load is reduced and the air conditioner doesn't have to work as hard.

The Summer Air-Conditioning Cycle: For summer operation, the air-conditioning cycle cools the air. The return air from the room passes over the surface of the cooling coil, and the air is cooled to the required temperature. If there is too much moisture in the room (high humidity), it is removed automatically as the air is cooled by the coil. The following example, Figure 3-2, illustrates the cooling and moisture removal process.

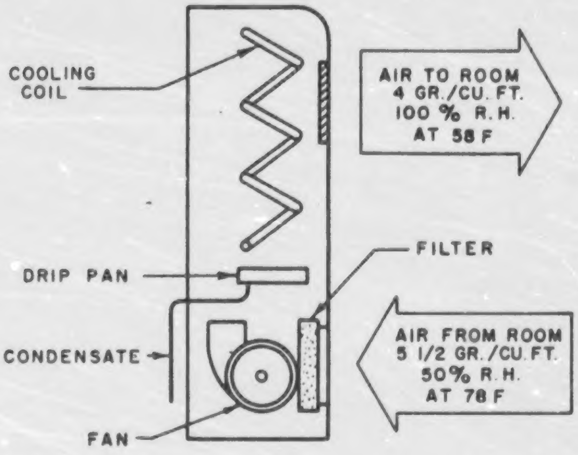


Figure 3-2

If air leaves a room at 78° F (see Figure 3-2), and holds approximately 5-1/2 grains of moisture per cubic foot, its relative humidity is 50%. (Air at 78° F can hold about 11 grains per cubic foot; therefore, 5.5/11 = 50% RH.) As the air passes over the cooling coil, it is cooled to 58° F. At this temperature, the air can hold only 4 grains of moisture per cubic foot. Since the air enters the coil with 5-1/2 grains and leaves the coil with only 4 grains, 1-1/2 grains of moisture are removed in the cooling process. The temperature of the supply air entering the room is now 58° F, and the moisture content is 4 grains per cubic foot. Although 4 grains is equivalent to 100% relative humidity at 58° F, the supply air is actually dryer by 1-1/2 grains than the 78° F air leaving the room.

As the supply air mixes with the room air, it removes heat and moisture, because it is colder and dryer. As a result, comfort conditions are maintained. If the cooling coil is sized properly, it provides enough cool air and removes enough moisture to offset (or balance) the heat and moisture that is constantly entering the room from a variety of sources such as the body, lights, motors, cooking, and outside air.

Humidity

Humidity refers to the amount of water vapor or moisture in the air. Warm air can hold more water vapor than cool air, so warm air speeds up evaporation. Relative humidity is a way of expressing the percentage of moisture contained in the air at a specific temperature. For example, 50% relative humidity means that the air is holding only half as much moisture as it is capable of holding at that temperature. Raising or lowering the temperature will change the relative humidity. In a sealed house, as the temperature rises, the relative humidity increases. If the temperature falls enough (as when the air circulates over a cold beverage glass), the relative humidity reaches 100% and water begins to condense out of the air, forming drops of water on the glass. High humidity and condensation can be undesirable in a home, making the air feel clammy, rotting window moldings, and rusting tools and equipment. On the other hand, low humidity makes the air feel dry, increases static electricity, and causes wood to dry and shrink. Consequently, both humidifiers and dehumidifiers are often used in homes to control the relative humidity to within comfortable limits. Since air conditioners also dehumidify the air by condensing and removing water vapor, it is desirable to select a unit with the right cooling capacity to control both the humidity and temperature of the home properly.

AIR MOTION AND VENTILATION

The motion of the air in a home plays many important roles. Too much air motion can make a home feel drafty, while too little air motion prevents uniform heating and cooling of the air. Air coming into the house from outside, and the subsequent loss of air from inside, is also a major source of heat loss and heat gain. Sometimes, this outside air is desirable, sometimes not. Fresh air can supply oxygen and remove stale odors, but most homes ordinarily have enough air entering through opening and closing of doors, so no additional air is needed. In general, air movement into and out of a home can occur in two different ways: ventilation and infiltration.

Infiltration air enters the home through cracks around windows and tiny openings in walls, ceilings, and floors. Hearing whistling noises around doors and windows while the wind is blowing hard is listening to infiltration air. The same is true when window shades move as the wind blows outside. This infiltration air is not intentional - a perfectly sealed home would not have any such movement. Since infiltration air must be heated and cooled, it contributes to the heating and cooling load of the home.

Ventilation occurs when air is intentionally brought into the home and made to mix with the air in the building. Ventilation air can be brought in by a separate fan, or it can be introduced using a special vent connected in the duct system. In either case, it is necessary to control not only the amount of outside air brought in, but its temperature as well. Many buildings are required by law or local building codes to have a certain amount of outside ventilation, especially nursing homes, hospitals, factories, and office buildings. The purpose of this ventilation air is to mix fresh air with circulating air in order to reduce the amount of odors, bacteria, and noxious gases.

Ventilation air also insures that an acceptable level of oxygen is present in the air.

The average home, though, does not need to have outside air brought in. The attic and crawl space, however, do require ventilation. Attic space usually needs ventilation all year round to remove heat buildup in summer and moisture in winter. The crawl space needs venting in the summer to remove moisture that would rot beams and produce musty odors. Such ventilation is not usually desirable in winter, because it increases the heat load and results in cold floors.

Ventilation in the furnace room is sometimes required by insurance and loan companies. This requirement is intended to prevent the furnace from burning up all the oxygen in the house. The furnace room is thus equipped with an outside vent to provide fresh air to the furnace burners, and combustion gases are then exhausted safely up the chimney. In many European countries, the vent is opened and closed automatically to increase furnace efficiency, but at present, this scheme is not approved in the U. S.

Basic Ventilation Requirements

Air is a mixture of gases. Normally, air contains about 21% oxygen. A human system requires that a certain oxygen content be contained in the air:

1. To maintain life.
2. To be comfortable.

If a room is tightly sealed, any human in that room would slowly consume the oxygen and increase the amounts of carbon dioxide, water vapor and other impurities. This could cause drowsiness or even death.

One must remember that space for human living must have air with a good oxygen content, and that this air must be kept at a reasonable temperature. It is of utmost importance that fresh air be admitted to provide the oxygen.

In the past, this fresh air entered the space by infiltration (leakage) from the outside at door and window openings, and through cracks in the structure. However, modern construction is reducing this air leakage. Air conditioning apparatus, then, must furnish fresh air. Modern units have a controlled fresh-air intake. This fresh air is conditioned and mixed with the recirculated air before it reaches the room.

Some conditioned air leaves a building through doors, windows and other construction joints. Some also leaves by exfiltration. (This means leaking out or being blown out by mechanical means.) Any kind of exhaust fan removes conditioned air. Some of this air is replaced by infiltration on those sides of the building exposed to wind pressure.

It is best to bring in replacement fresh air through a makeup air system. When this is done:

1. The makeup air can be cleaned.
2. The makeup air can be cooled or heated.
3. A positive pressure can be maintained in the building to keep out airborne dirt, dust and pollen. (A negative pressure reduces the efficiency of exhaust fans and fuel-fired furnaces.)
4. A definite amount of fresh air is brought into the building for health purposes (oxygen content).

Certain areas of a building should have a slightly less positive pressure (5-10%) than the rest of the building, to reduce the spread of odors. Such areas would include the kitchen, lavatories and where certain industrial operations produce fumes.

The amount of fresh air required depends on the use of the space and the amount of fresh air admitted by infiltration. One basic rule is to provide at least 4 cfm of fresh air per person to provide enough oxygen and to remove carbon dioxide.

One must remember that the air can be handled either to produce positive pressure (higher than atmospheric pressure) in a building, or negative pressure (below atmospheric pressure). A positive pressure will eliminate infiltration of air from outside or from other spaces. It is done by using special air intakes to the blowers. A positive pressure assures that all air entering a building can be filtered and cleaned before reaching the occupied space. Negative pressure increases the infiltration at windows and doors. This air is untreated and may be dirty.

Residential homes which use fuel-burning furnaces need air for combustion. Combustion air, leaving by way of the chimney, might leave the interior of the house under a slightly negative pressure. View B of Figure 3-3 shows a basic diagram of negative pressure conditions in a home.

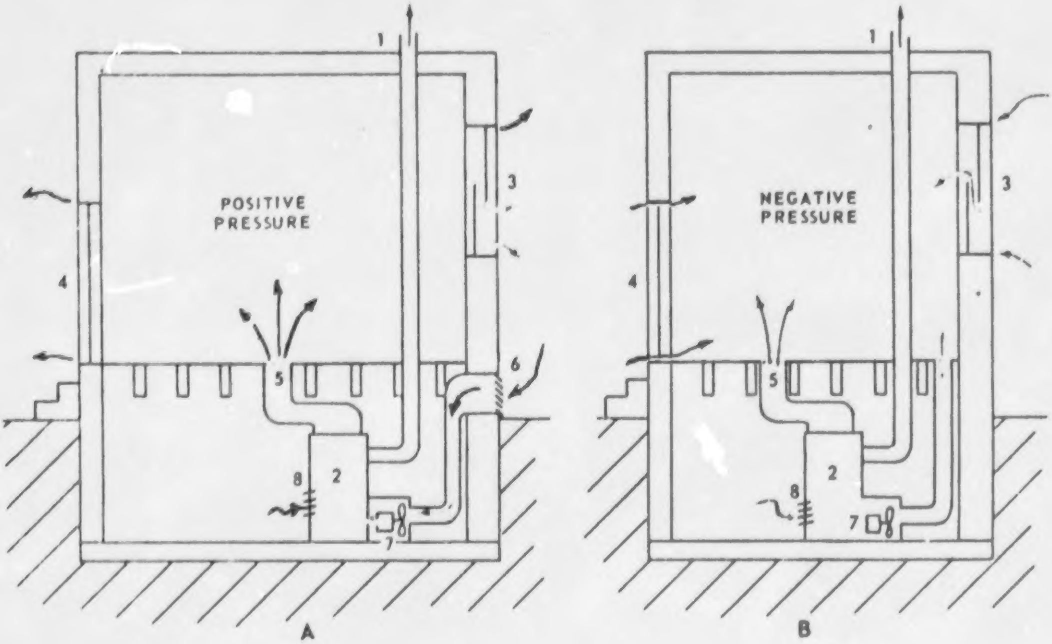


Figure 3-3: Simplified diagram of airflow into and out of a building during heating season. A-Positive air pressure. B-Negative air pressure. 1-Chimney. 2-Furnace. 3-Window. 4-Door. 5-Warm air grille. 6-Fresh air intake. 7-Fresh air fan. 8-Furnace draft control. The arrows indicate the airflow - both within the building and into and out of the building.

If the amount of impurities in the air - such as odor, smoke and bacteria - is great enough to require air cleaning, the remedy may be either ventilation, using fresh air, or improved air cleaning.

Ventilation is usually based on air changes per hour for the conditioned space. If the space is 1000 cu. ft., for example, three changes per hour would mean 3000 cu. ft. per hour or 50 cu. ft./min. Three changes every hour is the minimum for a residence during the heating season. As high as 12 changes an hour (in the above case, 200 cu. ft./min.) are recommended for cooling. Figure 3-4 shows typical air changes for both the heating season and the cooling season.

	Air Changes/Hour	
Use	**Heating**	**Cooling**
Homes	**3-6**	**6-9**
Offices **Stores**	**5-8**	**6-12**
Public Assembly	**5-10**	**6-12**

Figure 3-4: Recommended air changes for various types of occupancies.

It is good practice to keep the air blowers running all the time to provide good ventilation to all parts of the building. Variable speed blowers are sometimes used. They provide more air movement when the heating or cooling system is running; less movement when the systems are off.

An adequate air supply is the best way to control comfort. Body comfort is controlled by evaporation, convection, radiation, and respiration. One must, therefore, control the temperature of the walls, floor or ceilings to make sure they are not too warm or cold (radiation). One must also supply enough air to promote good respiration, evaporation and convection. If the specific conditions are not known, it is best to design for 2 cfm/sq. ft. and/or 12 changes/hr. It is also very important to remember that people occupying a closed space give off considerable heat. A sleeping person gives off about 200 Btu/hr., while a person doing heavy work gives off up to 2400 Btu/hr.

Another way to determine ventilation requirements is to design for 4 cfm to

6 cfm of fresh air per person, and for about 25 cfm to 40 cfm of recirculated air per person. This means the system should handle a total of 29 cfm to 46 cfm per person. One cfm = 0.0283 cu. m/min.

Air Infiltration: Let's look at the various ways that air infiltrates a house. Since the wind plays a major role in air infiltration, it is important to understand the dynamics of outside air movement and its effect on a structure. On the windward side, a positive pressure is built up, since the air is compressed; while on the leeward side, a negative pressure is created due to the suction of air away from that side of the house. See Figure 3-5. The pressure difference is one of the driving forces that creates air infiltration.

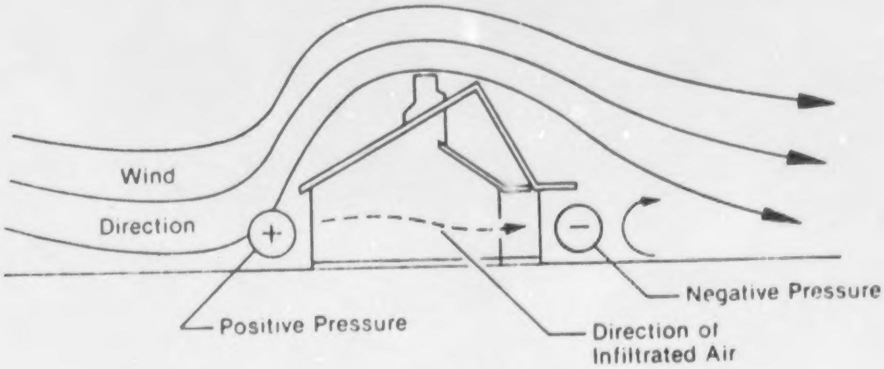


Figure 3-5: Wind Flow Patterns Over House

To analyze these conditions, we can consider air as similar to water flowing in a pipe. If the pipe is capped at one end, no water will "flow" regardless of the pressure applied. This same condition exists for air in a house; that is, there must be an inlet and an outlet for the air to travel through. Infiltrated air enters through cracks, walls and spaces on the windward or positive pressure side, and exits on the negative pressure side. The rate of air infiltration increases with increasing wind velocity; so with careful siting of wind barriers, you can slow down the winter wind reaching the house, or speed up a summer breeze to increase comfort. Knowledge of the seasonal prevailing winds and winter storm patterns will indicate where you should plant vegetation or construct winter windbreaks, and where to place your large and small windows.

Air infiltration also occurs if there exists a negative pressure within the structure. This condition is created by exhausting air for ventilation (i. e., the kitchen exhaust fan) or by venting a combustion unit to the outside. The oil burner or wood stove behaves in this manner; it takes air from an enclosed space, heats it in the combustion process, and vents it up the chimney. This results in a slightly negative pressure, which causes the outside air to infiltrate the house. Probably the worst offender in this regard is the charming, old-fashioned fireplace. I am sure that anyone who has ever sat in front of a fireplace can vouch for the fact that a steady stream of air from the room goes up the chimney. In fact, an average-sized fireplace will draw about 3000 cubic feet of air per hour - about a one-third air change per hour through the house. This is much more than will be drawn by an oil burner or tight wood stove.

The third mechanism of air infiltration is due to the difference in temperature (or density) between the outside and inside air and the vertical height separating the inlet and outlet openings. An exaggerated example of this type of flow is the operation of a chimney. Air flows from the bottom to the top because of the large temperature difference and the height of the chimney. Even with a small temperature difference over a short vertical height, however, a significant amount of air infiltration can occur. Figure 3-6, shown on the following page, illustrates the chimney effect and depicts how a house creates a similar air flow situation.

As we have seen, the three main causes of air infiltration into a structure are:

1. wind movement, which creates positive and negative pressure areas outside the house,

2. negative pressure within the house caused by various exhaust mechanisms, and

3. temperature differences between inside and outside air.

Of the three, the first (air pressure variations outside the structure) and the third (temperature differences inside versus outside) are the most significant.

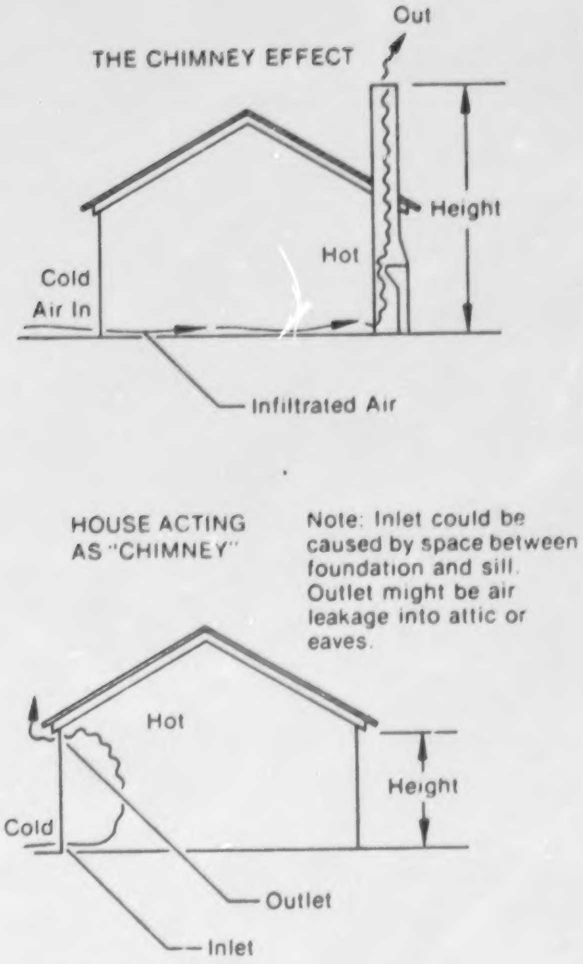

Out
THE CHIMNEY EFFECT
Height
Hot
Cold
Air In
Infiltrated Air
HOUSE ACTING
AS "CHIMNEY"
Note: Inlet could be
caused by space between
foundation and sill.
Outlet might be air
leakage into attic or
eaves.
Hot
Height
Cold
Outlet
Inlet

Figure 3-6: Infiltration Caused by the "Chimney Effect"

Reducing Air Infiltration: To reduce infiltration to a minimum requires several things. First, you'll want to reduce the speed of the wind outside your house with a windbreak, if possible. See Figure 3-7, which appears on the following page. While this is important, a full program of "tightening up" your house will have the greatest effect in reducing air infiltration, and hence your heating bills. This involves the use of a vapor barrier to prevent air from coming through walls and the application of caulking and weatherstripping around cracks, the foundation, floor, ceiling, windows, and doors. The relative importance of any of these areas will depend on the type of construction you have.

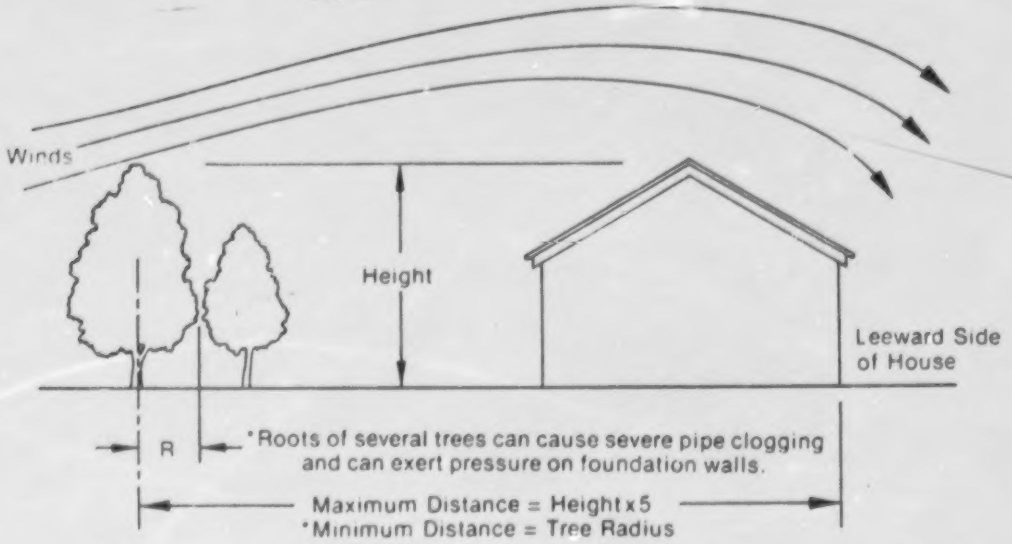

Winds
Height
Leeward Side of House
R
*Roots of several trees can cause severe pipe clogging and can exert pressure on foundation walls.
Maximum Distance = Height x 5
*Minimum Distance = Tree Radius

Figure 3-7: Wind Barriers

The best defense against air infiltration is to construct a tight house. You may be surprised to find out that air infiltration occurs not only through cracks but also through the walls themselves! This is because the pressure on the windward side forces air through the tiny holes in wood siding and even masonry walls. The solution for reducing air infiltration in this case is an effective vapor barrier. While designed primarily to keep water vapor within the living space, the vapor barrier is also an extremely effective barrier against air infiltration. To ensure the application of a tight vapor barrier when building a new home, stress its importance with your builder, or do it yourself. Aluminum-faced insulation is a very good vapor barrier, but you must make sure that there are no raised areas or "fish-mouths" when the insulation is stapled to the studs. You can also tape over the joint for a good seal. If polyethylene is used, make certain enough excess material exists at the ceiling and wall joints to prevent the polyethylene from being stretched or stressed when the interior covering is nailed in place. Watch out for rips or splits in the polyethylene (use 4 mil minimum thickness) and replace or repair these with tape.

For rehabilitation or renovation work where you are considering adding new interior surfaces, you can apply a polyethylene film first, and then put on your new wall. Plaster walls are effective vapor barriers, so you might want to repair cracks in existing walls. If your plans call for sprucing up the interior with paint, certain good quality paints serve well as vapor barriers. Ask your local paint supplier for a paint with a low permeability value or low air transmission properties. Another problem, in older homes, is that vapor barriers often are not tight near ceiling light fixtures, around cellar doors, attic access doors, etc. This permits large amounts of air to infiltrate into the house through the basement or first floor, while warm air exits through the attic vents. Make sure to seal up cracks like these with caulking or weatherstripping.

A good vapor barrier not only prevents air infiltration but also retains moisture in the house. Some people don't like the vapor barrier idea, though, since they feel that a house must "breathe." Actually, most houses "breathe" too much and are drafty. Additionally, any problems with moisture in the walls can be overcome by proper installation of vapor barriers. The barrier should always be placed next to the interior wall (on the warm side of the insulation material), as this arrangement allows air to circulate in the outer walls, thus reducing moisture problems, and will still be effective in reducing infiltration of air into the house. Watch out, though, as some builders will try to put the vapor barrier between the sheathing and the stud, and this will lead to a condensation problem in the wall and in your insulation. Remember, you want the moisture in the living space, not condensing in your insulation!

Thus, the windbreak, the vapor barrier, and the weather stripping and caulking help you to save money in several ways. They enable you to set your thermostat lower, because the comfort level in your house depends on the relative humidity as well as the temperature. The higher the humidity content in a room, the less moisture is given off by your body, and you feel warmer. So the first reason the vapor barrier helps is that by keeping house moisture inside, you can keep the thermostat down and less heat will be lost from the building. A second reason is that the vapor barrier reduces the amount of air infiltration into a house. Hence, less cold air must be heated. Yet a third reason is that the cold, dry outside air is excluded so it doesn't have the effect of lowering the humidity inside. Cold air has a much lower humidity content than warm air. If the infiltrated air isn't humidified, the indoor relative humidity falls below an accepted minimum level of 20%. At this humidity, a much higher temperature is required for thermal comfort. Taken together, the savings resulting from a full program of winterizing can be very substantial, some 30 to 50 percent of your heating bill!

The degree of tightness or air permeability has not yet been established by the building codes, and at present rests solely with the builder. Many people ask, "What if I make my house too tight? Will I be able to breathe?" The answer to this is that, using conventional building materials and techniques, you can't build a house so tight that lack of oxygen will be a problem! In fact, the amount of carbon dioxide is the controlling factor in the amount of air required for ventilation, and the tightest houses still let in more than adequate amounts of air. However, there have been houses built so tight that moisture builds up inside the house and becomes a problem. This situation can occur in houses constructed to use electric, solar, or heat-pump heating systems; or in houses heated by a combustion process (coal, oil, wood or gas), where the codes require direct furnace room ventilation via high and low wall vents so that sufficient amounts of air will not be drawn in and circulate throughout the house to avoid moisture buildup. So if you are worrying about the possibility of making your house too tight, stop worrying! If moisture builds up, you can open a few windows a little, to let the cold, dry air lower the humidity for those rare times when this is a problem; or you might want to install a fireplace. Then, if during the winter the house gets too humid, gather some firewood, light it, sit back, and enjoy it. Since your house is tight, you may want to open a few windows a bit to increase the fireplace draft. For example, if moisture in the kitchen is a problem, you can open a window, which will cause air to flow in through the kitchen and up the chimney. Working with the fireplace is more pleasurable than emptying pans from the dehumidifier, and has other charms as well.

Another question that people ask is about airing their house out. Occasionally, houses will need an "airing out" [illegible] removal of kitchen, bathroom, or other odors that build up in a tight structure. Rather than introducing outside air for odor control, you can use activated charcoal filters that can be installed in the air returns of forced hot air systems, over the kitchen range, or in conjunction with bathroom fans. For other types of heating systems, smaller units are available for individual room use. These filters work because of the large surface area in the charcoal. A 1-inch-thick by 1-foot square filter piece, for example, has effective surface area of over one million square feet! It's no wonder they are so effective in removing virtually all household odors. The filter units are inexpensive, last about 6 months to a year (depending on use), and are easily replaced. They can be used to remove just the worst kitchen, bathroom and tobacco odors, or can be used to purify the air in the house completely at all times. In the latter case, they also remove dust when used in conjunction with furnace filters, so household dusting can be all but eliminated as well. Thus, these filters make a tight house clean, pleasant, and economical to operate.

Summer Cooling and Ventilation: Summer cooling of your home by natural ventilation should be a prime consideration during your site planning and preliminary house design stages. Unfortunately, people's energies are usually focused on staying warm in the winter, and the opportunities for summer cooling are often overlooked. Recognition of the prevailing summer breezes and internal air flow patterns provides the information you will need to determine your summer cooling options. There are alternatives to expensive electric air conditioning, which is quiet, ecologically sound, and easy to install and operate. Since summer heat loads vary throughout the country, we will concern ourselves here with the principles of natural ventilation, which can be applied generally to various sites. If your climate is such that natural ventilation will not maintain the comfort level (such as in areas with almost no summer breezes), the principles discussed will still apply, so that your operational costs for a supplemental summer cooling system will be reduced. In these cases, you can open the windows and vents, to make the best use of the cooling breezes when they exist, and then use a fan or close the house off and use a room air conditioner on those days when the air is still outside.

Basically, the human body maintains a constant temperature (98.6° F) by giving up heat to its surroundings. This is necessary, since the body "burns" food for energy and must discard its excess heat. There are three ways in which heat is given off; radiant heat, convection to moving air, and evaporation of moisture from the skin. When the surrounding environment is too hot, too moist, or lacks adequate air movement, our body's heat-loss capability is reduced and we feel uncomfortably warm. Thus, a ventilating system should provide dry, moving air at a cool temperature. However, we cannot always achieve these ideal conditions because of varying climatic conditions. If, for example, you live in an area where the outside air is hot and humid, the only cooling effect you can hope to obtain, besides expensive air-conditioning, is by convection, which aids evaporation of moisture from the skin with high-speed air movement over the body. If, in another situation, the outside air is hot but with a low humidity, the body will lose heat through moisture evaporation from the skin at low air velocities. These climate conditions can vary considerably, so let's determine what we can do to obtain maximum cooling effects.

Shading Your House: Starting on the outside of the house, we first need shade trees to keep out the sun. Trees are the best natural cooling systems available, as they keep out the sun's heat rays, and the evaporated moisture from their leaves creates cool areas under their branches. Shade trees should be situated to protect the east and west sides of your house in the summer, since these sides are exposed to much of the sun's heat, and are difficult to shade, because of the changing location of the sun. Make sure that your contractor and bulldozer operator are aware of the trees that you want to retain. In monetary terms, the inconvenience and additional time spent in building by working around a good-sized shade tree will repay you in one or two summers. If you are planning the rehabilitation of an existing house, consider planting shade trees as a long-range solution for summer cooling.

Insulation and Ventilation: Once the house is shaded, the next major requirement is insulation. Yes, insulation also works for you in the summertime! What happens is that insulation increases the house's resistance to outside heat, so it takes longer for heat to get in. By the time heat does reach your living area, it is later in the day and the temperature outside is beginning to drop. Then cool evening air can be brought in to remove heat effectively from inside the dwelling.

The next step is to get these cool breezes into and through the house. Let's look at how to maximize the cooling effect with ventilation and where we want the air to flow. The factors involved with natural ventilation cooling are as follows:

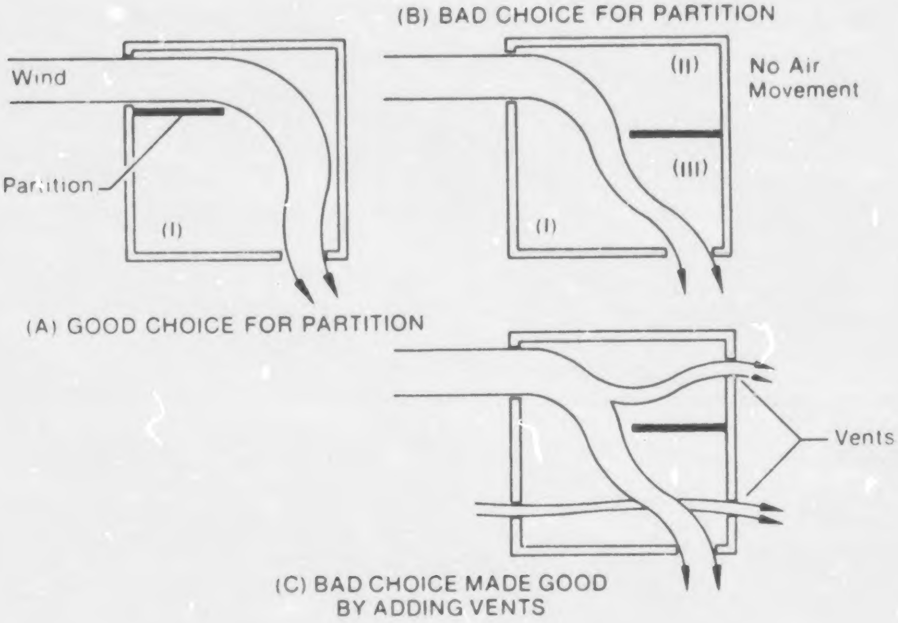
1. the summer prevailing wind velocity and direction,
2. the location from which we take air into the house,
3. the location from which air exits,
4. the time of day, and
5. the outside air temperature and humidity.

The installation of high and low air vents is one effective method of achieving summer ventilation. The hot air in your house will rise and exit from the high vent, while cool air will be drawn in through the low vent. The location of vents is important. You should try to have your intake vent on the windward side of the house and your outlet vent on the leeward side. In many instances the direction of the prevailing winds will vary during the day and night. If this applies to your site, plan to locate most of your inlet vents on the evening side to achieve maximum evening air flow, as the major cooling of your house will occur at this time. These vents must also be operable, so they can be sealed during the winter months and on hot sunny days.

Another consideration when placing vents is to minimize any impediment to the flow of air to the vents, such as shade trees or windbreaks. In the case of shade trees, the air will move freely to the vent as long as the crown of the tree is not in direct line with it. Make sure that the crowns of your shade trees are above these vents, or else install the vents on either side of the crowns. If there are conflicts with windbreaks because winter winds and summer breezes come from the same direction, you will have to balance these effects. Generally, the summer ventilation needs will be most important, as you can eliminate the windbreak and still minimize winter air infiltration by using other techniques. If a private outdoor patio is desired and the windbreak then serves to enclose this area, use vents along the wall area outside the protected patio area for ventilation.

Other important factors involved in achieving efficient air flow through a house are; first, the location of interior walls and, second, the size of operable windows and vents. This is because the speed of the air flow depends on the size and position of the inlet and exhaust openings (doors, windows, vents, etc.) and the speed of external cooling breezes. Natural cooling will occur when cool air is allowed to enter a house and replace warm air. Hence, by increasing the velocity of air passing through a structure, you increase the cooling effect.

Figure 3-8 shows the air flow patterns through a house and the effects of where walls and partitions are placed. As you can see in Figure 3-8A, the only region is I. With Figure 3-8B, regions I, II, and III feel little air movement. Be careful where you place your interior walls. Avoid placing partitions and openings in such a way that the wind gets trapped in dead ends. If the layout in your house is not ideal for this cross-ventilation, add vents to move air into the "still-air spaces" of your house. Figure 3-8C shows vents added to the layout of Figure 3-8B, substantially increasing summer comfort.

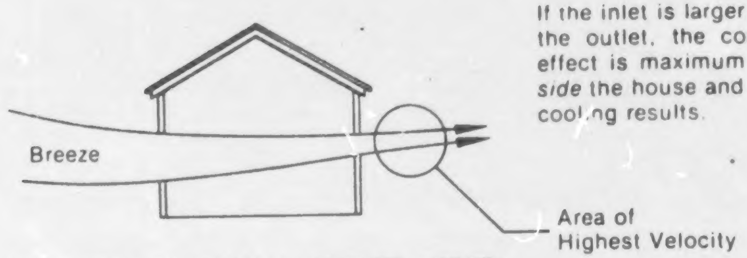

(A) GOOD CHOICE FOR PARTITION

(B) BAD CHOICE FOR PARTITION

(C) BAD CHOICE MADE GOOD BY ADDING VENTS

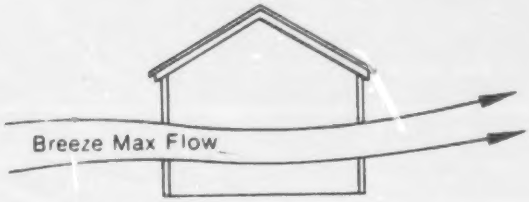
Figure 3-8: Partition Placement

Since air velocity through the house is needed for cooling, Figure 3-9 shows the effect of relative inlet and outlet vent sizes. Normally, maximum flow is desired, and, therefore the area of the exit opening should be at least as large as the inlet opening.



If the inlet is larger than the outlet, the cooling effect is maximum *outside* the house and little cooling results.

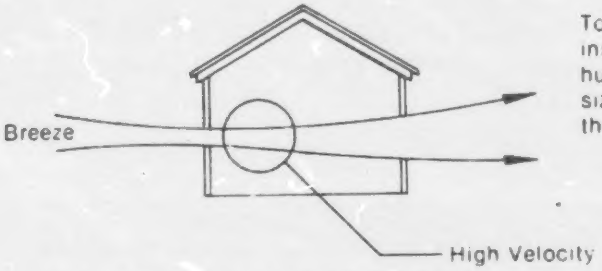
(A) LARGE INLET/SMALL OUTLET — POOR



When the inlet size equals the outlet, we get the full cooling effect of the breeze.

(B) INLET = OUTLET AREA — FAIR

If outside humidity is *high*, the most cooling will take place by increased internal air flow velocity. This is done by decreasing the inlet opening while leaving a large exit opening.

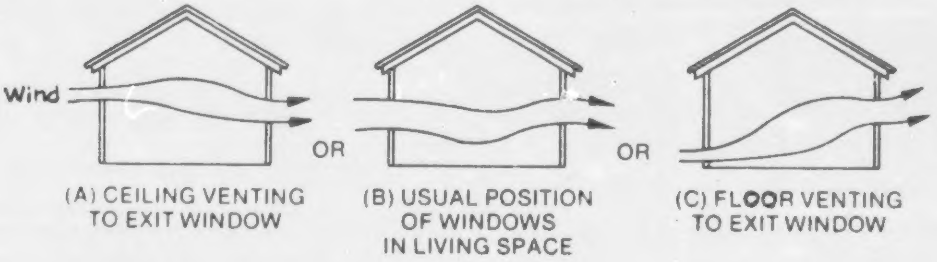


To get high velocity inside the house during humid days, reduce the size of the inlet to ½ of the outlet area.

(C) SMALL INLET LARGE OUTLET — GOOD

Figure 3-9

The final consideration is the height of vents or operational windows on the wall. Figure 3-10 shows the effect of various venting configurations. Note that, while the size of the outlet is important, its position on the wall is somewhat arbitrary, because you can vent any part of the room by adjusting only the position of the inlet vents. To decide which arrangement is best for you, first decide what area you want to vent. For example, if you want to vent the ceiling area, use the vents shown in Figure 3-10A; if you want to vent the floor area, use the arrangement shown in Figure 3-10C. As you can see, there are several choices. Generally, Figure 3-10C works best, since you benefit from the temperature difference (e. g., chimney effect) as well as from the wind movement, and the chimney effect can be increased even more by using high wall outlet vents and attic vents.



(A) CEILING VENTING TO EXIT WINDOW

(B) USUAL POSITION OF WINDOWS IN LIVING SPACE

(C) FLOOR VENTING TO EXIT WINDOW

Figure 3-10: Any Part of the Room Can be Vented by Adjusting the Position of the Inlet.

The decision to use a fan will be determined by your local climate conditions. Generally, humid southern regions of the country require a high volume of air movement through the house, since the major cooling effect is due to air velocity passing over the body. In regions with low humidity, on the other hand, cooling will take place by evaporation of moisture from the skin, so a lower air volume will produce a comfortable cooling effect.

One area you'll want to make sure to ventilate is the attic; in winter, for condensation control, and in summer for reduction of daytime temperatures. A trap door can be used to allow hot air in the living area to vent through the attic. The best ways to vent the attic is by using a continuous vent along the ridge and eaves, or by installing turbine ventilators in your roof (see

Figure 3-11).

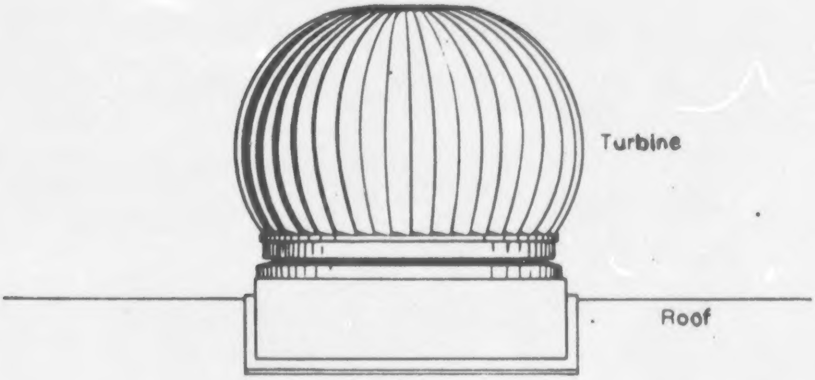


Figure 3-11.

An attic fan is also a good investment, since it will reduce attic temperatures during those windless summer days when the sun is shining; in the evening, it can be used to bring in cool night air. See Figure 3-12, which appears on the following page.

The size of the fan will vary with the site, but for a rule of thumb, southern regions can design for up to one air change in two minutes; in northern climates, one air change per three minutes should be adequate. Thus, for a house in a southern climate with a volume of 10,000 cubic feet, the fan size can be found by dividing 10,000 cubic feet by 2 minutes, or 5,000 cubic feet per minute. This is the "ventilation rating" you want, not the free air capacity. The latter describes the fan's maximum output; that is, without any load. As you start to load the fan with resistance (i. e., ducts, louvers, screens), the actual air movement will be greatly reduced. A well-built fan will give you years of service with little maintenance, so look for quality when you buy. Look at the name plate or product literature, as you'll want a fan that meets what are called the ASHRAE or NEMA test standards. As with all rotating electrical equipment, safety precautions are a primary concern. Check your local building codes for the electrical and fire regulations regarding attic fans, and use safety guards when persons, especially children, might have access to the fan.

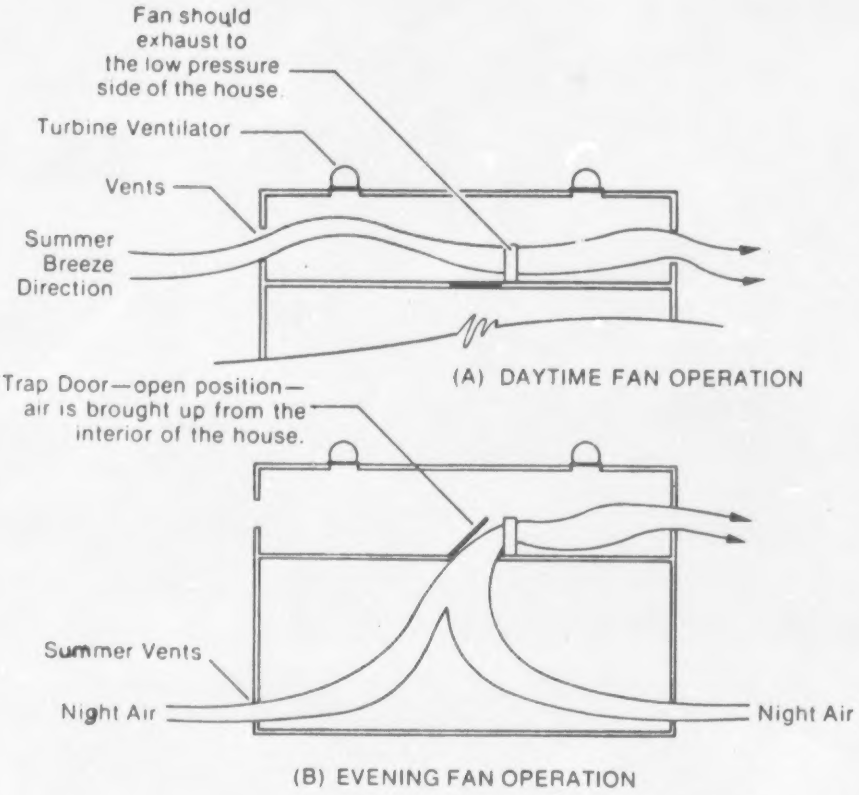

Fan should exhaust to the low pressure side of the house.
Turbine Ventilator
Vents
Summer Breeze Direction
(A) DAYTIME FAN OPERATION
Trap Door—open position—air is brought up from the interior of the house.
Summer Vents
Night Air
Night Air
(B) EVENING FAN OPERATION

Figure 3-12.

What do you do in situations where there are few summer breezes? In this case, it will pay to take as much advantage as possible of the chimney effect (the fact that heat rises) by using floor-to-floor vents, together with low inlet vents and high outlet vents along walls, in the top floor ceiling, and in the attic. This way, hot air will rise up through the house bringing replacement air into the house behind it. This "breeze" effect will give some comfort in these situations and can be improved upon by placing shade trees, a pond, or groundcover on the inlet side, so that air is cooled by the evaporation of water from these areas before it is drawn into the house. On hot, still days, when this method isn't enough to satisfy your needs, the attic fan mentioned earlier will bring the air speed in the house up to the comfort level.

HEATING AND HUMIDIFYING

All heating and air conditioning systems have a common purpose; treating air to maintain comfortable levels of temperature and humidity (moisture content).

In the past, houses were heated by an open fireplace or stove, and ventilation was accomplished by opening doors and windows. Today, more attention is being given to maintaining the proper temperature in a house, and the correct moisture content in the air as well, as it is increasingly recognized that both have a bearing on health and comfort.

It is important to recall a few facts about heat - that, for example, it is constantly on the move in one of the following ways:

> Conduction: Heat will always leave an object that is warm for one that is less warm, and it will always flow in the direction of the cooler object. When heat passes through the walls and room of a house, it travels by "conduction".
>
> Convection: Air tends to rise when it is heated, so warm air always rises to the ceiling of a room while the cold air drifts down. The current formed by warm air's tendency to rise is called "convection".
>
> Radiation: The traveling, or transference, of heat from one object directly out into the air is known as "radiation".

These three characteristics of heat are the basis, in varying degrees, of all our present home heating systems.

Central heating systems are those general systems which create the heating for an entire building at one central point. The heat is then delivered to the places where it is required. There are two main kinds of central systems. The first is "indirect" or "warm-air" heating. In the second, "steam" or "hot-water" is carried by pipes to radiators, where the heat is given off.

Most central heating systems burn coal, oil, or gas, or are powered by electricity. Coal, gas, and electricity are burned or consumed directly. Oil is changed into a fine mist, which burns when it is mixed with air. Most central heating systems today are automatically controlled by a thermostat. When the temperature drops below a certain point, the thermostat makes an electrical contact, which turns the burner or heater on. When the temperature reaches a higher point, the thermostat turns the heat source off or down.

Unless a heating system is operating at maximum efficiency, money is lost. Any time a furnace is out of adjustment or the air circulation is restricted, the heating efficiency is reduced and the operating cost is increased. Once it is understood how a heating system works and how to size a unit for a particular need, it will be easy to correct and even anticipate common problems that affect heating system efficiency.

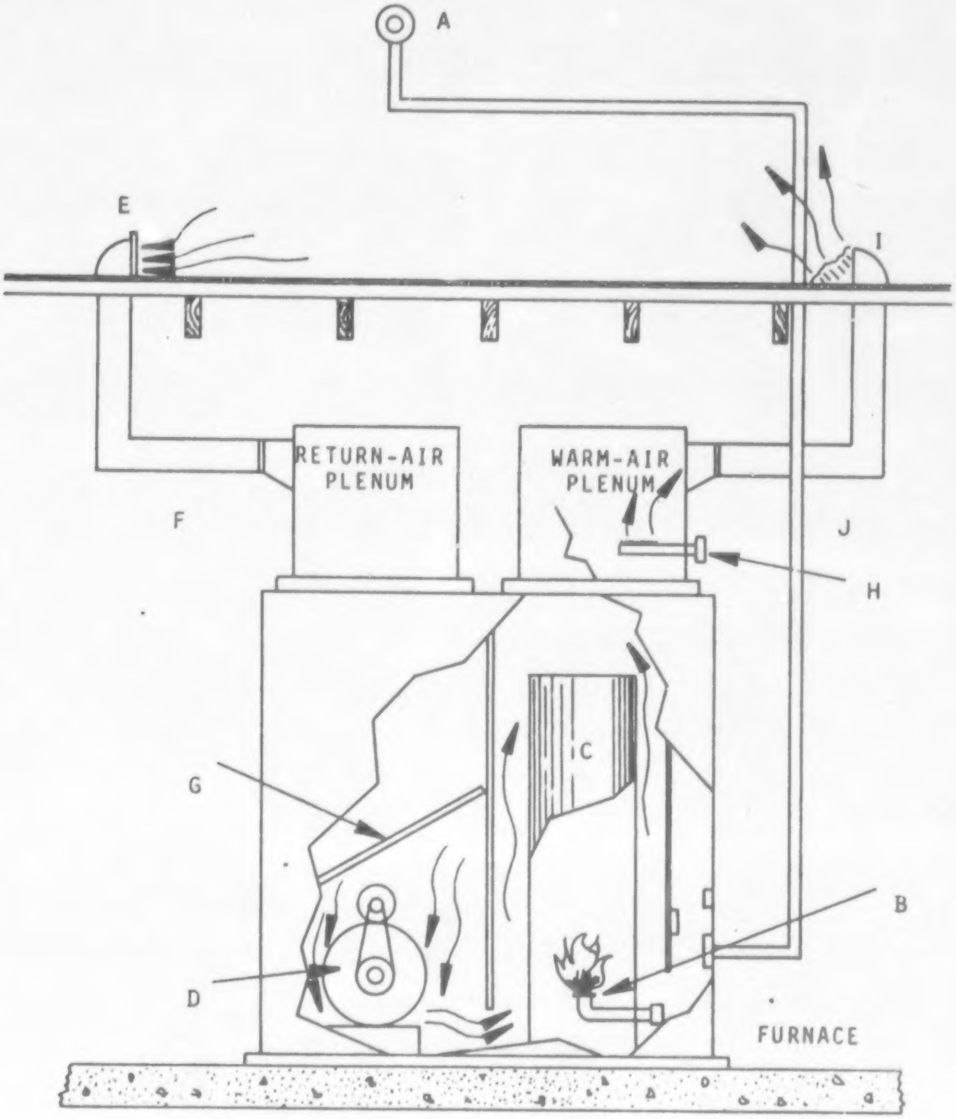
Forced-Air Components

A central heating system consists of a furnace, which serves as the source of heat; a fan, to distribute the heated air; and ductwork, to provide a path by which the air travels. Figure 3-13, shown on the following page, illustrates how a forced-air system operates in principle.

All forced-air systems operate similarly . . . and automatically. When room temperature drops below a pre-determined minimum setting of the thermostat, (A), the burner (B) starts, and heats the air around the heat exchanger (C) in the furnace. When the temperature of the air in the furnace reaches the "fan on" setting of the fan control, the furnace blower (D) starts. The blower pulls the cool air from the rooms through the grilles (E), and return-air ducts (F) to the furnace. Here, the air passes through the filters (G), and circulates around the heat exchanger, where it warms and picks up moisture from the humidifier (H). The cleaned, moistened, and warmed air is then delivered to the registers (I) in each room, through the warm-air ductwork (J). When the thermostat is satisfied, the burner automatically shuts off. The fan control should be set so that the blower runs almost continuously during cold weather. Cost of continuous blower operation is little more than for intermittent operation, and gives more comfortable, uniform heating, with little chance of air stratification. A control automatically turns off the burner if the furnace overheats.

Sizing a Heating System

Sizing a heating system means selecting a furnace and piping large enough to replace the natural loss of heat from the home. To do this properly means knowing some details about the house and local weather conditions.


A
E
I
RETURN-AIR PLENUM
WARM-AIR PLENUM
F
J
H
C
G
B
D
FURNACE

HEATING SYSTEM

Figure 3-13.

Each house must be surveyed individually, because its size and construction is different from any other house. Houses lose heat through exposed ceilings and floors, outer walls, windows and doors. Heat is lost through each of these areas at a different rate because of sizes, types of materials, and use of insulation or storm sash.

All factors are reduced to a common measurement of heat - the British Thermal Unit (Btu). This makes it easy to match a proper size furnace or boiler (outputs expressed in Btu) with the heat loss of any house (also expressed in Btu).

Each geographical location has a design temperature for heating. This is not the lowest temperature recorded, but the lowest temperature reached during 97-1/2% of the time - the only practical approach in designing heating systems.

The most important point to be stressed in sizing and designing a heating system for a particular home is to install equipment that is no larger than required. This concept is relatively new and has gained impetus since the oil embargo of 1973 and the increasing fuel costs. It is not uncommon for buildings built prior to 1974 to have heating systems and circulation fans designed three times larger than the heating requirements. In addition to consuming more energy, oversized equipment results in short periods of operation, poor comfort conditions, and lower seasonal efficiency.

Ideally, output capacity of heating equipment should not be less than the calculated heating load. And, it should not exceed the calculated heat load by more than 15%. Cooling equipment output capacity should be no less than five percent below the calculated cooling load, nor more than 12% in excess of the calculated cooling load.

Many times, however, it is not possible to obtain equipment within these limitations. If this is the case, then the homeowner should consider the possibility of reducing the heat loss and heat gain of the structure to the point where properly sized equipment can be obtained.

Final selection of heating equipment depends upon the type of system selected, the location of the system in the structure, and upon the equipment itself.

Fuel Costs

Once the heat load of a home has been established and the size of the heating system has been designed, the type of heating system to install must be determined. This question is predicted on the type of fuel available in a particular area, and the fuel costs for operation.

All energy sources are sold in units, such as the gallon, the cubic foot, or the kilowatt-hour. The cost per unit doesn't tell what it actually costs to heat the house. To figure this, one must know how much heat energy one can get from one unit of each energy source. That is, how many Btu are produced from each unit bought. This information is given in Table 3-2.

COMMON FUELS AND THEIR HEAT ENERGY PER UNIT

FUEL	UNIT	BTU PER UNIT
natural gas	cubic foot	1,000
	therm (100 cu. ft.)	100,000
propane	gallon	90,000
butane	gallon	130,000
No. 1 fuel oil	gallon	136,000
No. 2 fuel oil	gallon	140,000
electricity	kilowatt-hour	3,413

NOTE: Propane and butane are gases that become liquids when pressurized, and are sold by the gallon. Liquid petroleum gas (LPG) is a name commonly applied to both propane and butane, or even a blend of the two. In general, propane is used in the north, while butane is used in the south.

Table 3-2.

Fuel costs can then be estimated by using the following formula:

$$C = \frac{F \times E}{P}$$

Where

C = cost per Btu of heat energy, in Btu per dollar

F = Btu value of fuel

E = efficiency of your heating system, in percent

P = price of fuel, in cents per unit.

Heating System Efficiency

There are several types of fuel used in heating systems. Table 3-3 shows the efficiencies of several of the most popular heat sources.

HEATING SYSTEM EFFICIENCY

HEAT SOURCE	EFFICIENCY
wood furnace or stove	30-50%
coal furnace	30-60%
natural gas furnace	75-80%
propane furnace	75-80%
butane furnace	75-80%
oil furnace	75-80%
electric furnace	90-100%
electric baseboard	95-100%

Table 3-3.

The efficiency of a heating system is based on the amount of heat energy that actually goes into the living area, which is compared to the total amount of heat generated inside the furnace. Not all the heat generated goes into the living area - some of it goes up the flue, and some of it is lost in the ductwork as the heat passes through unheated parts of the house. The advantage of electric heating is that no flue is needed, since there are no exhaust gases due to combustion. Electric baseboard heaters, for example, have an efficiency approaching 100%, because practically all of the heat generated inside them is delivered to the area being heated.

Fuel Furnaces: Fuel furnaces must have flues to expel the combustion fumes, and these flues unfortunately carry away large amounts of heat energy. Wood-burning units have the lowest efficiency rating - as much as 70% of the heat produced from the burning wood is wasted as it goes up the flue. Coal furnaces are almost as inefficient.

Therefore, the flue damper is directly involved with the efficiency of the heating system. Ideally, a fuel-burning furnace needs only enough air to assure that all of the fuel is cleanly burned. Not enough air will prevent the fuel from burning completely, producing soot and dangerous carbon-monoxide fumes. Too much air, on the other hand, only cools the combustion temperatures and carries more heat up the flue. Hand-fed heating systems are therefore very inefficient because the damper setting must also be controlled by hand, reducing the efficiency to about 30%. If an automatic feeder and automatic damper are added, however, the efficiency of these units can be increased to about 50%.

Natural gas, propane, butane, and oil furnaces have efficiency ratings of about 80%. If the gross input Btu to a furnace is listed as 100,000 Btu, one would expect the net figure given as 80,000 Btu. But in practice, one could achieve a slightly higher net heating capacity with a finely tuned furnace - and a much lower output with a poorly tuned one.

The higher efficiencies of gas and oil furnaces are due primarily to their construction. The amount of fuel fed into the furnace is carefully and automatically controlled when properly adjusted. The heat exchanger in such furnaces is also constructed to extract the maximum amount of heat energy from the hot gases produced as the fuel burns. Finally, the air flow through the combustion chamber is regulated by dampers to insure good combustion of the fuel. However, if the furnace is not properly adjusted and cleaned for maximum heat transfer, one cannot expect to obtain good heating efficiency.

If the air flow to the burner of a gas or oil furnace is not correct, the efficiency can drop to less than 50%. The flame of a gas furnace should be a bright blue color. If it is yellowish in color, the air flow could be adjusted too low, or it may be that the gas pressure is too high; if the flame is erratic or jumps off the burner, the air flow may be adjusted too high, or the gas pressure may be incorrect. When the adjustments are not correct on an oil-burning furnace, the flame smokes, causing problems with smut build-up in the flue or chimney.

Air flow through the heat exchanger in a furnace is also quite important. If the heating ducts or cold air returns are too small, the furnace will not deliver its rated heat capacity. A safety thermostat on the heat duct leaving the furnace prevents the air temperature from exceeding safe levels. If the temperature rises too high, the high-temperature-limit thermostat turns off the burners until the air temperature drops to a safe level again. If the burners on the furnace turn ON and OFF even though the room thermostat is demanding more heat, that means the limit thermostat is operating, and this in turn indicates that there is probably not enough air flow through the ductwork.

Every forced-air furnace has air filters in the cold air intake to prevent dust particles from collecting in the furnace and ductwork. If dust collects in the burner box, heat conduction to the air is not only decreased, but a fire hazard is also created. If one smells scorched air from the heat registers, it is likely some dust has gotten into the burner box. A clean air filter will assure maximum air flow through the furnace.

The actual efficiency of a heating system will depend on several factors:

1. Properly adjusted burners.
2. Clean nozzles and jets.
3. Correct fuel pressure at the nozzles and jets.
4. Clean fuel filters.
5. Clean air filters.
6. Properly adjusted nozzle and jet openings.
7. Correctly sized supply and return air ducts.
8. Well-lubricated furnace blower.
9. Automatic (rather than manual) furnace operation.

If any of these factors is out of line, the efficiency of the system will drop, wasting both fuel and money.

Electric Furnaces: Electric furnaces resemble fuel furnaces, but differ because no combustion takes place. As a result, there are no burner adjustments to make and no flue pipe to waste heat. An electric furnace, therefore, requires little maintenance to keep the unit operating at maximum efficiency of 90-100%.

Electric furnaces, however, have much in common with fuel furnaces when it comes to the ductwork and blower that circulates heated air throughout the house. For this reason, most of what has been said about the size of the ducts, clean air filters, and routine maintenance also applies to electric furnaces.

Because of the relatively high cost of electricity as compared to other fuels, the efficiency of an electric furnace system is of paramount concern. Heat losses cannot be tolerated, and every step must be taken to insulate and seal the home thoroughly. Most of the heat loss occurs in the duct system, so it is important to insulate and seal ducts passing through garage areas and open crawl spaces properly. Most all-electric homes are built with considerably more insulation than other homes to offset the higher cost of electricity, so adding more insulation to the house is usually a good idea.

Electric Baseboard Heaters: An electric baseboard heater may operate at nearly 100% efficiency, since there are no fans and no duct systems to waste heat. This assumes, however, that the unit is wired properly and is perfectly clean. The efficiency of a baseboard heater will be reduced if the heating element gets dirty, thus reducing the transfer of heat that should go into the room. Baseboard heaters should be cleaned with a vacuum cleaner at least once a year to avoid this problem.

Maintenance

Filters: All central heating systems have filters. These filters all get dirty - that's their job! They take the dust and lint particles out of the circulating air so dirt does not clog the working parts of the furnace. The air filter is usually located in the return air duct where the cool air enters the furnace to be heated. As the filter removes the dirt from the air, the filter itself becomes clogged and restricts the air flow, cutting down on both the efficiency and capacity of the furnace. Filters should be checked every month and either cleaned or replaced.

Fans: The fan most used in heating systems is the squirrel cage fan. This fan circulates the air through the furnace and duct system. Over a period of time - even with regular filter replacements - the blades and motor of the fan will become covered with dirt, reducing air flow in the furnace. Clean the fan blades with a brush and soapy water. Be careful not to move any of the balance weights from the fan blades.

Gas Furnaces: A gas furnace may burn natural gas (methane), propane gas, or butane gas. Natural gas is delivered to the house through underground gas lines, while liquid petroleum gas (LPG) is stored near the house in supply tanks with direct feed lines to the furnace. The gas flow to the furnace is regulated by a gas valve in the line, which meters the amount of gas entering the burners within the heat exchanger. Air is mixed with the gas there and is ignited to produce heat.

To get the highest amount of heat energy from the furnace, the gas and air mixture must be just right. To accomplish this feat, a series of regulators control the flow of gas to each burner, and each burner has an adjustment mechanism to control the air flow.

Gas Valves Manifold: The gas valve controls the flow of gas into the manifold, a pipe which connects the gas valve and the burners. Gas flows from the valve into the manifold, which distributes the gas to the burners. When the furnace is not heating and the thermostat is not calling for heat, the gas valve is closed. When the thermostat calls for heat, an electrical solenoid in the gas valve opens, permitting gas to flow through the valve into the manifold. If the pilot light goes out, the gas valve will close to safely prevent gas from escaping into the furnace room and house. The gas valve closes when the pilot light goes out because the thermocouple, a temperature-sensing device, is no longer heated by the pilot light.

If a leak develops in the gas valve, gas can enter the furnace and room even when the pilot light is off. This not only wastes gas and money, but it can also be very dangerous, leading to fire or explosion. Therefore, check for gas valve leaks.

Adjusting the Air Mixture: The flame in the burner should be bright blue in color close to the burner. If the flame is not burning correctly, the first place to check is the air adjustment. When there is not enough air, the flame will usually have a yellowish color. This means the flame is not burning hotly, so it will take more gas than it should to heat an area. Too much air causes the flame to burn with a pale blue or white color.

Cleaning the Burners: Burners must be kept clean because if the air flow is out of adjustment on the burners for a long time, soot may collect around the burners' openings. The flame may even burn inside the burner body or at the gas jet opening and build up carbon and soot insude the burner. Sometimes dust and lint in the air will also collect in the throat of the burner and partially block the air flow. In damp locations, the burner can become spotted with rust.

Clean the burners with compressed air to remove dirt, lint, and loose soot. If the burners are oily, wipe them carefully with a cloth, but be careful not to bend or break the burners. As a last resort, if there are some really tough buildups of soot, use a cleaning solvent to dissolve the dirt.

Adjusting The Gas Pressure: The gas pressure also affects the mixture of the gas and air going to the burners. If one has tried adjusting the air flow to the burners, has cleaned the burners, is sure that all gas connections are tight, and still has a flame that does not burn properly at the burners, the gas pressure may not be correct. A sure indication of pressure problems is a flame that is too large or too small.

To measure gas pressure, a special gauge is used to indicate the pressure in inches of water, indicated by the height of the water column in a glass tube. Gas companies and repair services have them. Do not attempt to adjust the gas pressure without using the proper set of gauges.

Adjusting The Pilot Light: The pilot light in most gas furnaces burns continuously, although a form of electric ignition is used on some newer furnaces. Before adjusting the pilot light, it's a good idea to inspect it to insure that it is reasonably clean. A dirty or clogged pilot is often responsible for the pilot light going out, and a pilot light that is too small often causes noisy ignition of the burners. To clean the pilot light, remove it from the burner assembly.

Some forms of electric ignition use a hot wire to ignite the pilot, which then heats the thermocouple, which in turn allows the burners to turn on. Oil furnaces generally use arc igniters to light the fuel. Electric ignition systems can save fuel, but problems can also develop with these. In hot-wire systems, for example, the wire element can fail, but this is easily replaced with a new unit. An advantage of such systems is that the pilot and thermocouple parts are not on most of the time, so they do not have to be cleaned or adjusted as often.

Electric Furnaces: An electric furnace will usually operate properly and at maximum efficiency for many years without adjustment. Since there is no fuel combustion taking place, there will not be problems with carbon and soot build-up. Thus, any dirt that could decrease efficiency in an electric furnace must come from the air circulated inside the house. Keeping the air filters clean is therefore an important part of maintaining an electric furnace. Since there is no combustion, the electric furnace also has no flue to waste heat energy. As a result, almost all of the heat produced by the furnace elements ends up in the house.

Heat is generated in an electric furnace by passing electric current through resistance wires. When these heating elements raise the temperature of the air enough in the heat chamber, the fan starts and circulates the warmed air throughout the house. These electric heating elements draw a great amount of electrical power, so it is essential that adequately sized wires are run to the furnace to supply all the current needed. Normally, local building codes insure that the proper size of wiring is used, since the current passing through these wires also produces heat, which is wasted.

Maintaining The Fan: The fan controls on an electric furnace are usually preset and cannot be adjusted. The switches that turn the fan ON and OFF, for example, are sealed units mounted in the heat chamber. The limit switch is usually a metal fuse (rather than a circuit breaker), and melts when the furnace elements get too hot. Consequently, if the fan does not come on for some reason, the fuse will open, requiring that it be replaced after the fan is repaired.

About all one can do in maintaining an electric furnace is to keep the fan blades, fan motor, and filters clean. If a regular maintenance schedule is kept, few problems will be encountered.

Checking The Thermostat: An electric furnace usually has a special two-stage thermostat that prevents waste of energy. For example, consider an electric furnace with four heating elements. When the thermostat calls for heat, the first two elements come on immediately. The second two elements will not turn on unless the thermostat senses a big drop in temperature, or unless the first two elements do not heat the house fast enough. This technique gives some energy savings to the homeowner, because the second two elements are not used until they are needed.

Sometimes an outside thermostat is also attached to the two-stage thermostat inside the house. In this system, if the temperature outside remains above a preset temperature (usually about 35° F), the second stage of the thermostat cannot come on.

Space Heaters

For a small house or apartment in areas with mild winters, a heating unit such as a wood stove, coal stove, fireplace, gas heater, oil heater, propane heater, or electric space heater can be more economical than a central furnace.

When choosing a space heater, keep safety and energy use in mind. Electric heaters should be considered last because they are heavy users of energy. Non-electric heaters should be properly vented. If venting is inadequate or the adjustments faulty, deadly quantities of carbon monoxide may be produced. Many states prohibit unvented units because of this hazard.

A space heater should have a guard around the flames or coils to protect children, pets, and clothing from the heat source. Allow adequate clearance on all sides of the unit.

To keep the heater in good working order, inspect it regularly for needed adjustments, dust or dirt, cracks, faulty legs, and hinges. Keep the electrical wiring in good condition.

For Safe Operation of Space Heaters:

Keep a window partially open if an unvented unit must be used. Fresh air will prevent the accumulation of gas fumes.

Use only the fuel the heater is designed for. Do not convert to another fuel without consulting an expert.

Keep children away from space heaters and stoves.

Be certain the fire has proper ventilation to maintain a constant rate of burning that gives moderate heat - not too hot or too cool.

Always keep a screen around any heater that has open flames.

Keep the damper open while fuel is burning. This will provide for efficient burning and will prevent accumulation of explosive gases.

Learn how to light a gas heater properly. If someone smells gas, gurn off all controls and open a window. Don't allow gas to accumulate. If a heater fails to light on the first try, allow sufficient time for the gas to dissipate before trying again.

Never keep flammable liquids around heaters. Vapors can be ignited by the open flames.

Use heavy-duty cords for electric heaters. Have an electrician check the wiring if a heater uses higher than usual wattage.

Never place an electric heater near a bathtub, shower, or sink. Don't touch one when wet.

Place a metal sheet under the unit to protect the floor from live coals, burning, or overheating.

The fireplace is used today primarily as an enjoyable addition to a home. Watching the flames can bring peace to the heart and soothe the soul. Even more importantly, however, the fireplace can be used to supplement central heating. On cool days, the fireplace might provide the necessary heat to take away the chill.

The most energy-efficient fireplace will have warm-air vents through which hot air can be spread around the room or through ducts to other rooms. A modified fireplace with a fan can also help circulate hot air effectively.

To obtain maximum efficiency from a fireplace, be sure the chimney is working as it should. If the chimney is too low, the draft will not be strong enough to pull out the smoke. Keep the chimney clear of ashes, and be sure the flue is operating properly.

Solar Heating

Solar energy is rapidly becoming a logical alternative source of heat as the cost and unavailability of conventional fuels become a major problem in industrial countries. Getting heat from the sun is not a new idea - most people have experienced getting sunburned on a cloudy day, much to their surprise, so the energy is there. And now, technology has brought the cost of harnessing the sun closer to being economically competitive. Add the fact that solar heating is very attractive environmentally, and one has strong reasons for considering the solar systems as alternatives to conventional heating systems. Collecting, storing and using solar energy for space heating requires the control of air or liquid flow, or both.

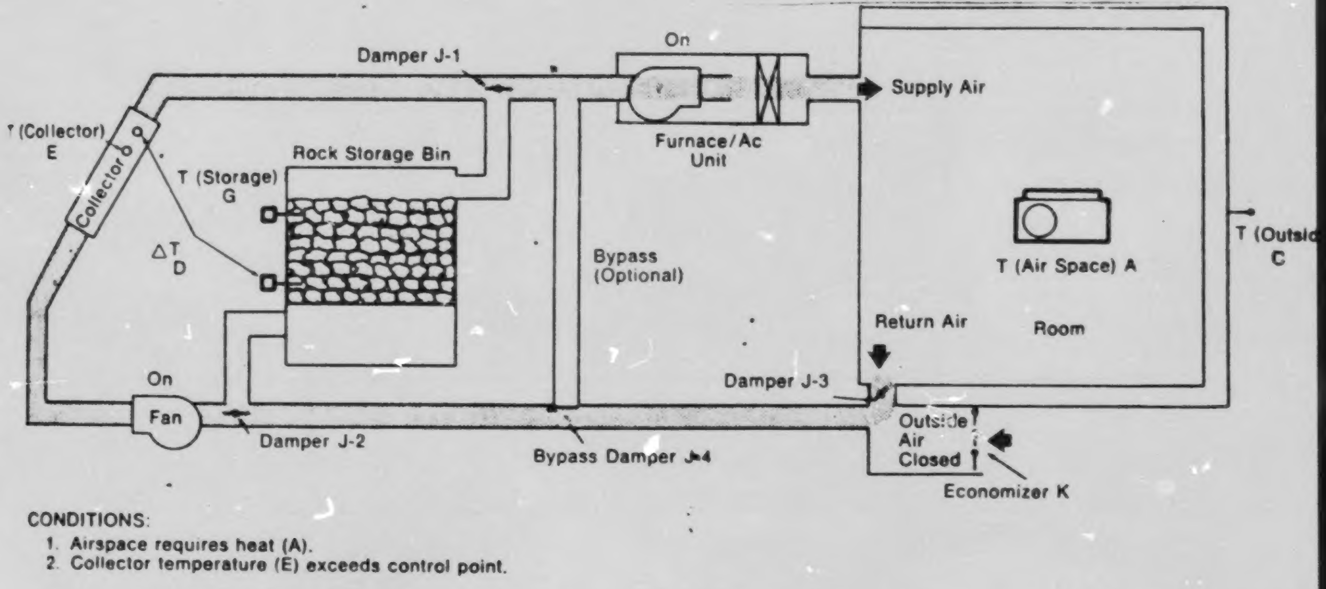
All-Air Systems: There are four essential operating modes for a solar assisted air system:

1. space heating directly from collectors,
2. space heating from storage,
3. space heating from auxiliary, and
4. storing heat.

A two-stage room thermostat is typically (but not always) used to sense space temperature and initiate demand. The first stage usually operates the solar system and the second stage operates the backup heating system.

Heating Directly From The Solar Collectors: When the sensor in the discharge air stream of the solar collector indicates that the collector temperature exceeds a pre-determined point, and the room thermostat is demanding heat, then the operating mode is as shown in Figure 3-14, which appears on the following page.

The duct arrangement shown in Figure 3-14 indicates a two-blower system. This is fairly typical, although a single-blower configuration is also used (see Figure 3-15, also on the following page). More exotic designs may even include three blowers. Also, for simplicity, manual and back draft dampers are not illustrated.


Damper J-1
On
Supply Air
T (Collector) E
Collector
Rock Storage Bin
T (Storage) G
Furnace/Ac Unit
ΔT D
Bypass (Optional)
T (Air Space) A
T (Outsid C
Return Air
Room
On
Fan
Damper J-3
Damper J-2
Bypass Damper J-4
Outside Air Closed
Economizer K

CONDITIONS:
1. Airspace requires heat (A).
2. Collector temperature (E) exceeds control point.

Figure 3-14: Heating Directly From Collectors of an All-Air System

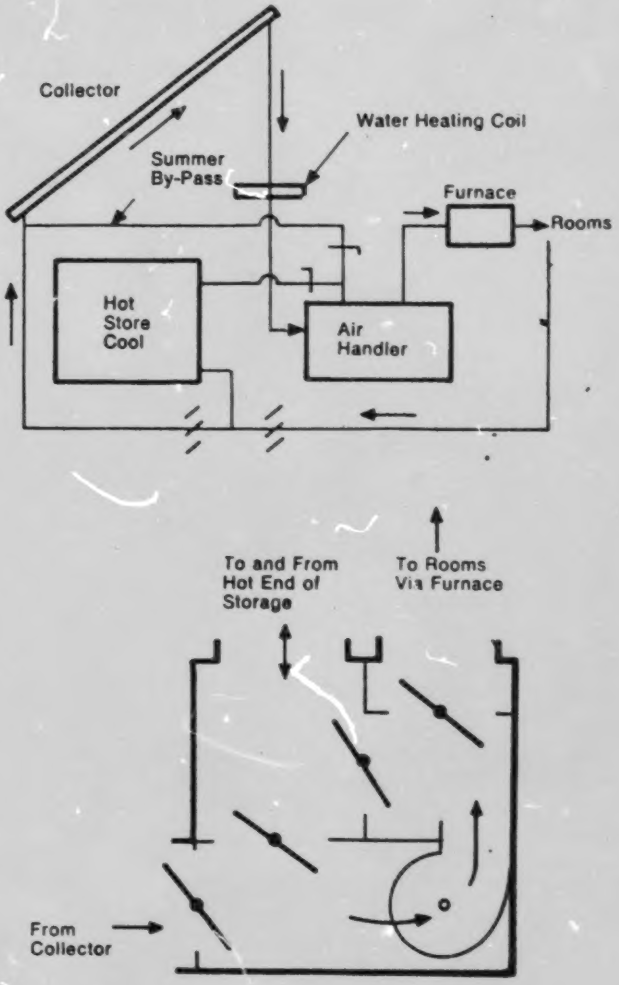
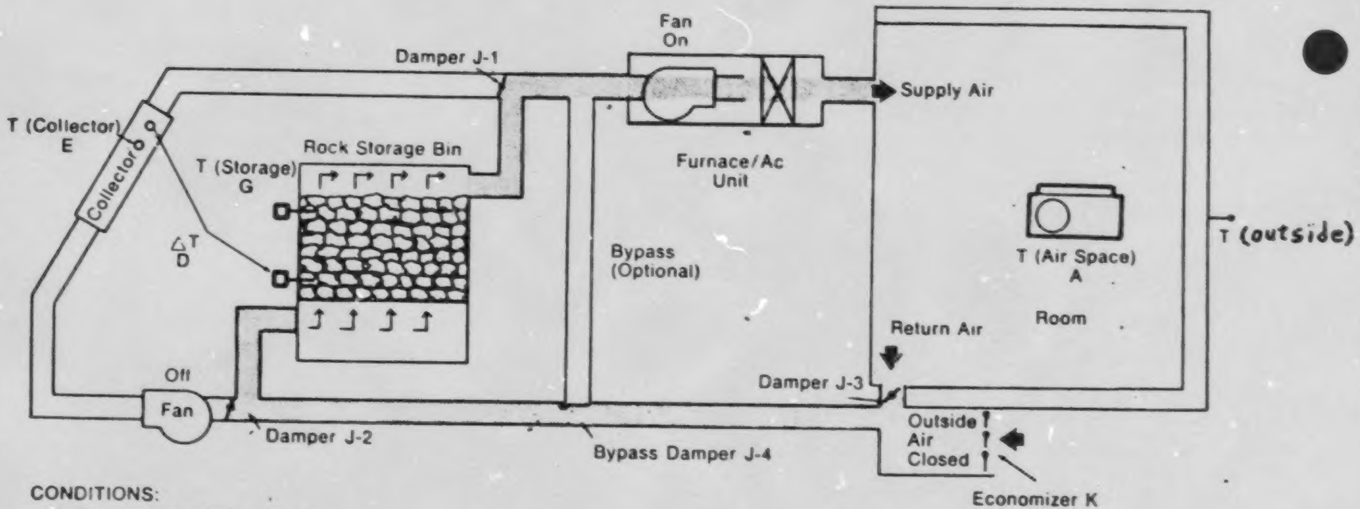

Collector
Water Heating Coil
Summer By-Pass
Furnace
Rooms
Hot Store Cool
Air Handler
To and From Hot End of Storage
To Rooms Via Furnace
From Collector

Figure 3-15: Air Handler, Single Blower System Design. (Sketch Shows Use in Complete System).

For the arrangement illustrated in Figure 3-14, dampers J-1, J-2 would be positioned to isolate the storage circuit, damper J-3 would be opened, and the economizer would be closed. The air flow path would follow the shaded area, provided collector flow rate and auxiliary heating air flow requirements were the same. If there is a difference in air flow requirements, then the bypass damper, J-4, would be opened and some portion of the air flow would circulate through the bypass duct. Thus, if collector air flow was 800 cfm and the auxiliary furnace/AC unit required 1200 cfm, 400 cfm would flow through the bypass duct. In this mode, both the furnace fan and collector fan are operating.

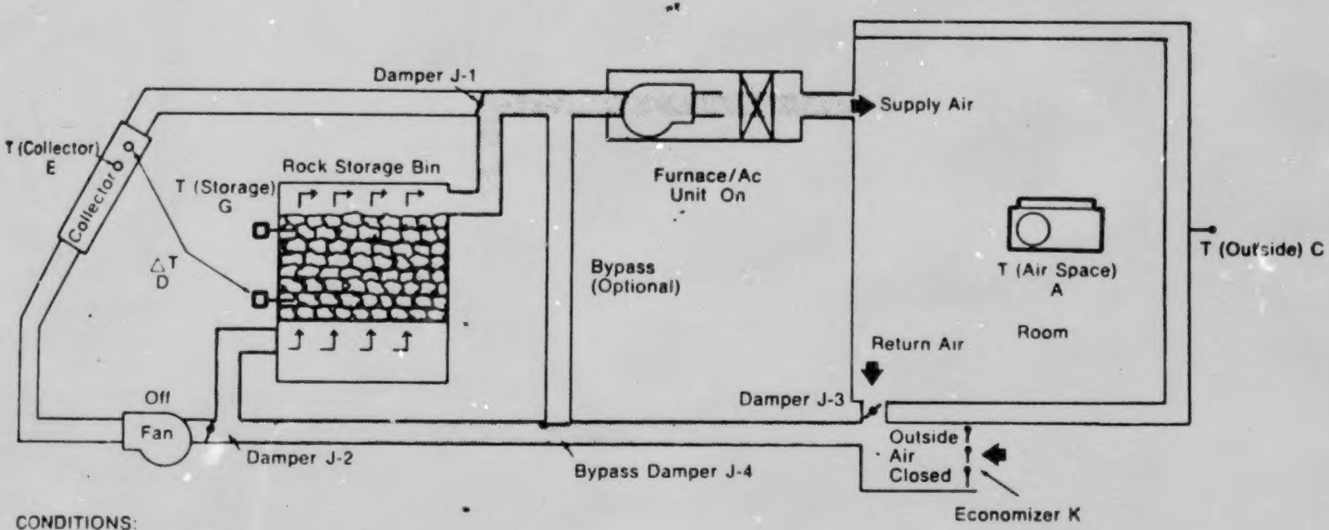
Heating From Storage: When the collector air temperature is below a predetermined set point, and the storage temperature is above a specific point (e. g., 90° F or above), then dampers J-1 and J-2 are repositioned to direct the air through the rock storage unit. At this time, the collector fan would shut off. (See Figure 3-16.)


Fan
On
Damper J-1
Supply Air
T (Collector)
E
Collector
Rock Storage Bin
T (Storage)
G
Furnace/Ac
Unit
T (outside)
△T
D
Bypass
(Optional)
T (Air Space)
A
Room
Return Air
Off
Fan
Damper J-3
Damper J-2
Bypass Damper J-4
Outside
Air
Closed
Economizer K

CONDITIONS:
1. Airspace requires heat (A).
2. Collector temperature (E) is below control point.
3. Storage temperature (G) is above control point.

Figure 3-16: Space Heating From Storage

Heating With Auxiliary Furnace/AC Unit: In most instances, when the temperature drops in the rock storage and fails to satisfy space heating needs, the space temperature will drop and the second stage of the room thermostat will close to start the auxiliary heating. This unit may be a gas, oil or electric furnace, or perhaps a heat pump. Figure 3-17 illustrates the flow path for this mode.

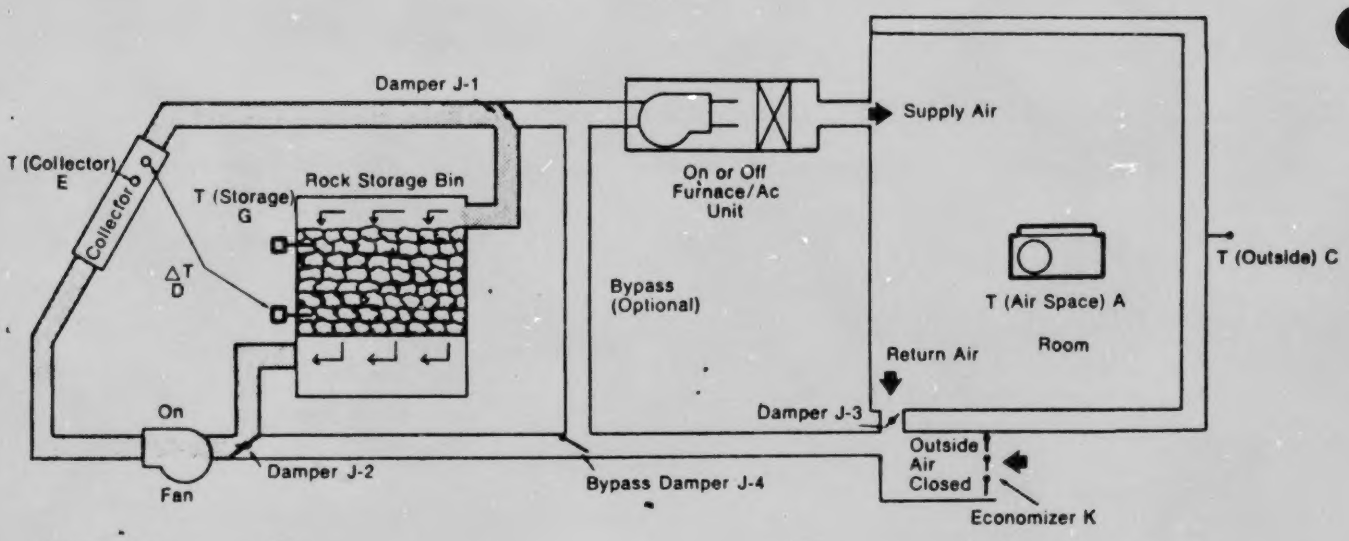

Damper J-1
Supply Air
T (Collector) E
Collector
Rock Storage Bin
T (Storage) G
Furnace/Ac Unit On
ΔT D
Bypass (Optional)
T (Outside) C
T (Air Space) A
Room
Return Air
Off
Damper J-3
Fan
Outside Air Closed
Damper J-2
Bypass Damper J-4
Economizer K

CONDITIONS:
1. Airspace requires heat (A).
2. Collector temperature (E) is below control point.
3. Storage temperature (G) is below control point.
4. Furnace is energized by 2nd thermostat stage (A).

Figure 3-17: Heating Using the Auxiliary Heating Unit

Storing Heat: When there is no demand for heating from the first stage of the room thermostat but there is collectable heat, the system switches to the heat storage mode. Figure 3-18, on the following page, shows the flow path. In this mode, dampers J-1 and J-2 are positioned to route the discharge air from the collector through the pebble-bed storage. The collector fan is on and the auxiliary furnace fan may be either on or off, depending on the use of CAC (Continuous Air Circulation) or cycle fan operation.

Note that the flow path for storing heat is reverse of the path used to remove heat during the heating from storage operating mode. This flow path direction is essential to take full advantage of the temperature stratification, which occurs in the rock storage. This permits the hottest air to be utilized when heating from storage.


Damper J-1
T (Collector) E
Collector
T (Storage) G
Rock Storage Bin
ΔT D
On
Fan
Damper J-2
Bypass Damper J-4
On or Off Furnace/Ac Unit
Bypass (Optional)
Supply Air
T (Air Space) A
Room
Return Air
Damper J-3
Outside Air Closed
Economizer K
T (Outside) C

CONDITIONS:

1. Airspace doesn't require heat (A).
2. Collector temperature exceeds storage temperature (D).

Figure 3-18: Storing Heat

In a typical operation, the collector fan would be turned on whenever the temperature difference between the air entering and leaving the collector exceeded 20 degrees, regardless of a demand for heat from the room thermostat. Dampers automatically adjust for the storage mode, and heat storage continues until the room thermostat calls for heat.

Hydronic Systems: Liquid (hydronic) solar heating systems operate basically the same way as air solar systems. The most basic difference is the addition of a liquid-to-water heat exchanger in closed systems. Also, some liquid systems are arranged so that the modes of operation are simply:

1. storing heat,

2. heating from storage, and

3. heating by auxiliary.

Space heating directly from collectors is not possible.

One disadvantage of systems that eliminate direct collector heating is that collectors must always operate above storage tank temperature and, hence, at a higher inlet temperature. This lowers collector efficiency.

In systems where heating from the collector is provided, lower temperature water can be used to heat the space effectively, thus increasing energy utilization. To take full advantage, however, the terminal (space heating) device must also be able to utilize low temperature water to heat successfully. This usually rules out hydronic baseboard units sized for 220° F water, and many liquid systems use duct coils to transfer heat to circulating air. (Radiant floor panels operating at 110° F are another possible option).

Figures 3-19 through 3-21, which are shown in the following pages, illustrate a typical hydronic-to-air solar heating system with most specialty items omitted for clarity. Accompanying Figure 3-19 is a table which summarizes the condition of each pump and blower in the system for each operating mode.

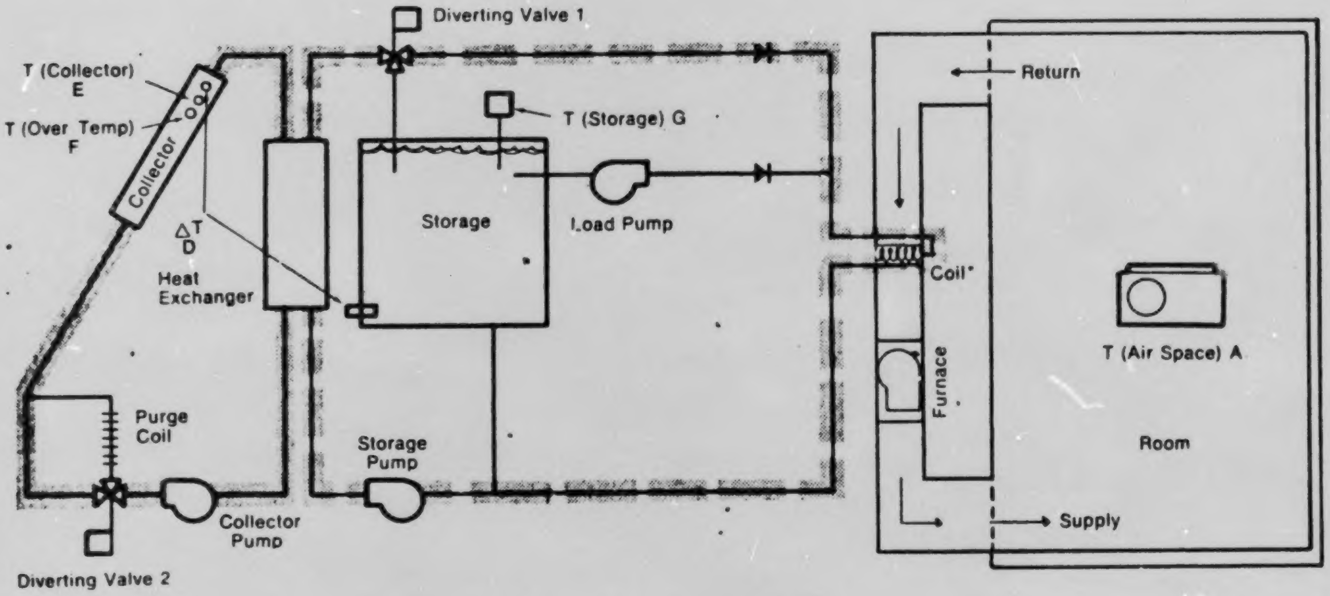
Sensors in the collector and solar heated water storage tank, along with a thermostat located in the space to be heated, provide the necessary information to a central control unit. Based on the information (electrical signals) received, the central control unit opens or closes valves and activates the appropriate pumps and/or blowers. This control system makes the system completely automatic.

Heating From The Collector: In Figure 3-19, space heating is being accomplished from the collectors. The room thermostat has indicated a need for heat and the sensor in the collector is above some predetermined point, for example, 90° F or higher. The collector pump and storage pump are turned on and the liquid/water flow is as indicated through the duct coil. The furnace or air handler blower is also on, to circulate room air over the now hot coil.

Heating From Storage: In Figure 3-20, the room still requires heating, but the collector temperature is below the control point, while the storage temperature exceeds its control point, again perhaps 90° F. Both storage and collector pumps are stopped, and the load pump is started to take heat from storage and circulate it through the duct coil.

Storing Heat: Figure 3-21 illustrates the heat storing mode. Space conditions are satisfied, but the temperature differential between the collector and storage is high enough, 20° F for example, to initiate collector and storage pump operation. Diverting valve one is activated to divert the discharge from the heat exchanger into the top of the storage tank. The storage pump removes cooler water at the bottom of the tank and recirculates it through the heat exchanger to be heated.

Operating Mode	Storage/Collector Pumps	Load Pump	Auxiliary Heater	Blower
Storing Heat	On	Off	Off	Off
Heating from Storage	Off	On	Off	On
Heating by Auxiliary	Off	On or Off	On	On

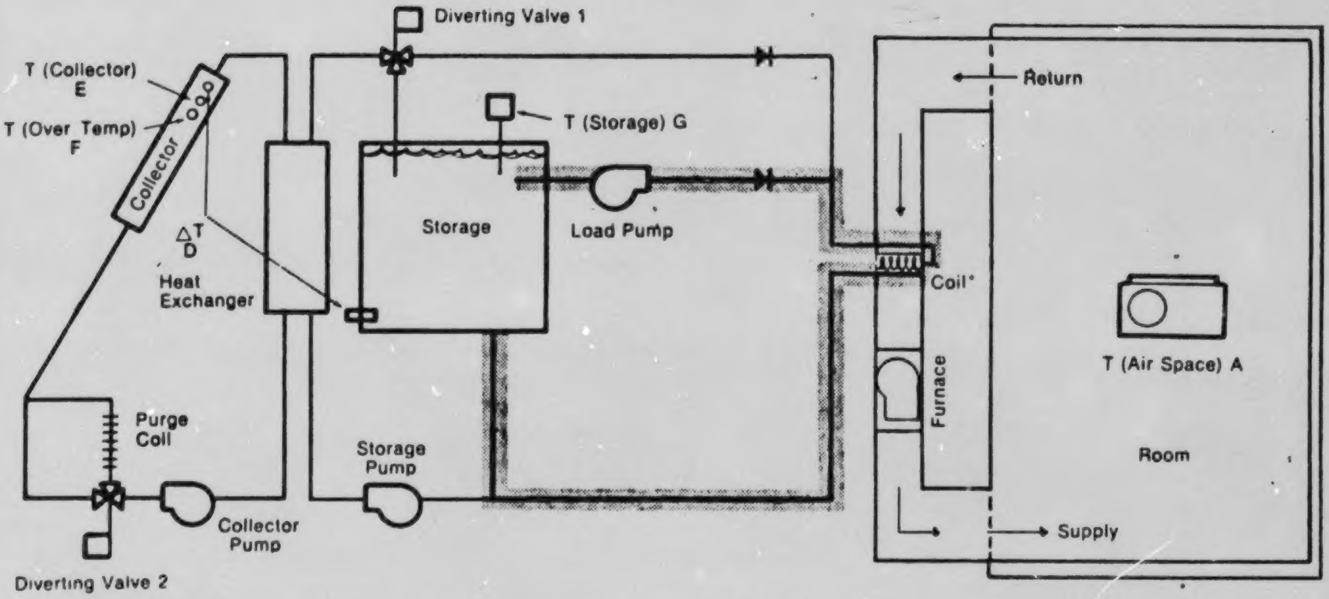

Diverting Valve 1
T (Collector) E
T (Over Temp) F
Collector
T (Storage) G
Storage
Load Pump
ΔT D
Heat Exchanger
Return
Coil*
Furnace
T (Air Space) A
Room
Purge Coil
Storage Pump
Collector Pump
Diverting Valve 2
Supply

* NOTE: If heat pump is used, solar coil is placed downstream from heat pump coil.

Conditions:

1. Airspace requires heat (A).
2. Collector temperature (E) exceeds control point.

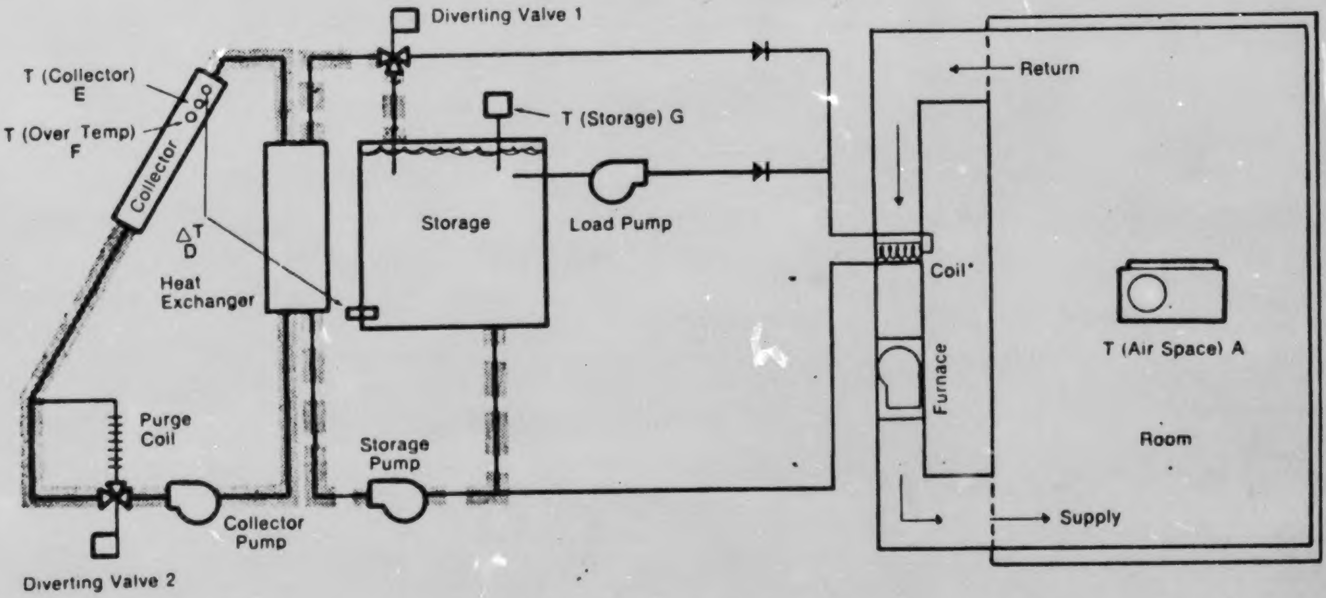
Figure 3-19: Heating From The Collector


Diverting Valve 1
T (Collector) E
T (Over Temp) F
Collector
T (Storage) G
Storage
Load Pump
ΔT D
Heat Exchanger
Return
Coil*
Furnace
T (Air Space) A
Room
Purge Coil
Storage Pump
Collector Pump
Supply
Diverting Valve 2

* NOTE: If heat pump is used, solar coil is placed downstream from heat pump coil.

CONDITIONS:
1. Airspace requires heat (A).
2. Collector temperature (E) is below control point.
3. Storage temperature (G) exceeds control point.

Figure 3-20: Heating From Storage


Diverting Valve 1
T (Collector) E
T (Over Temp) F
Collector
T (Storage) G
Storage
Load Pump
ΔT D
Heat Exchanger
Return
Coil*
Furnace
T (Air Space) A
Room
Purge Coil
Storage Pump
Collector Pump
Supply
Diverting Valve 2

* NOTE: If heat pump is used, solar coil is placed downstream from heat pump coil.

209

CONDITIONS:
1. Airspace does not require heat (A).
2. Collector temperature exceeds storage temperature ΔT (D).

Figure 3-21: Heat Storage Mode

Humidifiers

Relative humidity is the percentage of moisture in the air relative to the amount of moisture the air could hold at that temperature. People generally feel uncomfortable when there is too much or too little moisture in the air. During the summer, for example, a relative humidity of more than 70% makes the air feel damp, close, and sultry. During the winter, a relative humidity of less than 30% makes the air feel dry, irritates the nose and throat, and encourages the buildup of static electricity in rugs, upholstery, and clothing. Dry air also makes the air feel cooler, because it speeds up the evaporation of moisture from the body.

During the heating season, it is difficult to maintain a suitable level of humidity because the cooler air outside the home contains very little moisture. For example, if the temperature is 50° F outside with 100% relative humidity, the humidity will drop to less than 20% by the time the air has been heated to 70° F. For outside temperatures below freezing, the air contains practically no moisture. For this reason, the relative humidity in your home will be very low during the coldest winter months.

Many schemes have been tried for increasing the humidity level in a home during the winter. You can boil pans of water on the stove, hang wet clothes to dry in the basement, drape wet towels over radiators, set water-filled pans on the floor, etc. But if not inefficient, these methods are messy, to say the least. Most modern furnace humidifiers require a minimum of maintenance, and a selection of models is available in a wide price range.

All humidifiers should be inspected once a year before the heating season begins. Evaporator-type humidifiers should also be inspected a couple of times during the winter to be sure that accumulations of lime and minerals from the evaporating water do not clog the water-inlet valve or the fins, belts, and bristles.

As water is evaporated from the humidifier, lime and mineral deposits are left behind. These collect on the valve seat, so they must be removed periodically. If they are not, the valve may not close, causing the water basin to overflow.

To clean the humidifier, first remove it from the bottom of the duct. You can drain the water from the basin of the humidifier through the drain hole in the bottom. Scrape all the mineral deposits from the float, the valve, and the valve seat. Remove the mineral deposits from any other part of the humidifier and water lines.

Operation and Maintenance: Read the owner's manual. Place the unit near a room partition and allow six inches behind it for circulation. Avoid small rooms, heat sources, and corners. The bottom of a stairway is a good location.

For the first few days, adjust at high settings to moisten air, walls and furniture. Turn down as dampness develops.

Set humidistat at a level for personal comfort.

Disconnect the unit when filling or cleaning the water reservoir. Be sure the area and unit are dry before reconnecting the cord.

Do not pour hot water in the reservoir or overfill it.

Dust the grilles every week with a soft brush.

Every few weeks, empty the reservoir and scrub the inside with a sponge and a mild detergent to prevent mold, mildew, and bacteria.

Clean the filter pad monthly.

Fuel Savings: For years, it has been common knowledge that people feel warmer when the humidity in a room is higher. Generally, you can figure that each 10% increase in relative humidity enables you to turn down the room thermostat by about one degree. This would seem to indicate that a substantial fuel savings can be obtained by using a humidifier, but one has to be careful about such claims. The savings are not as great as some manufacturers would have their customers believe.

You will remember that, when water evaporates, it absorbs heat energy. Your furnace has to supply this heat energy when you use a humidifier - and it takes over 8,000 Btu to evaporate just one gallon of water. Fortunately, however, the average size home needs less than one gallon of water evaporated into the air to bring the relative humidity from 0 up to 50%. Since there are many other sources of water vapor in your home, your furnace humidifier does not have to supply very much water each day to maintain the humidity at a comfortable level. Of course, this depends upon how much infiltration air enters your home, pushing out the moist air. The more tightly sealed your home is, the more moisture it will be able to retain, and the less water vapor the humidifier will have to add to the air to replace what was lost.

Energy Conservation

The U. S. Department of Energy has outlined tips for saving energy in heating. This list serves as a summary of conservation measures available to the homeowner when considering heating the home.

Heating and cooling homes account for most residential energy costs. Don't waste energy costs. Don't waste any of that precious conditioned air (whether you pay for it yourself, or you pay your landlord for it).

During both heating and cooling seasons . . .

Close off unoccupied rooms and shut the heat or air conditioning vents; or turn off room air conditioners. (This does not apply if you have a heat pump system. Leave it alone; closing vents could harm a heat pump.)

Use kitchen, bath, and other ventilating fans sparingly. In just one hour, one of these fans can blow away a houseful of warmed or cooled air. Turn them off just as soon as they have done their job.

Keep the fireplace damper closed unless a fire is burning. An open damper in a 48-inch fireplace can let up to 8% of the heat out the chimney.

Heating Energy Savers

Don't turn the heat on until necessary. On cool evenings, use the fireplace instead, and add an extra blanket at night.

If using an electric furnace heating, consider a heat pump system. The heat pump uses thermal energy from outside air for both heating and cooling. Costs for these pumps run from about $2,000 for a whole-house unit, to about $425 for room size, but they can cut your use of electricity for heating by 30-40%, and also can provide some savings in cooling costs.

If planning to buy a new gas heating system, ask the gas utility or public service commission about the savings potential of electronic ignition. Ask also about possibilities for retrofitting any older system in use.

Consider the advantage of a clock thermostat for the heating system. The clock thermostat will automatically turn the heat down at a regular hour before you retire, and turn it up again before you wake. While it is easy to turn the thermostat back at night and up again in the morning, the convenience of a clock thermostat may be worth the $70 to $90 cost.

Consider buying a properly sized furnace that incorporates an automatic flue damper. This device reduces the loss of heat when the furnace is off. (Contact the gas utility or oil supplier for guidance).

Don't use the fireplace for supplemental heating when the furnace is on unless taking one of the measures suggested below to lessen the loss of heated air from the house.

The warmth from a fire on the hearth generally doesn't radiate through the house. The heat gain is confined to the room with the fireplace, and, when the furnace is also on, a considerable amount of heated air from the rest of the house is drawn into the fireplace, and goes wastefully up the chimney. Thus, the temperature in other rooms of the house goes down, and the furnace uses more fuel to raise it to the level controlled by the thermostat. Thus, more rather than less fuel is needed, when both the furnace and fireplace are in use.

Lessen heat loss when using the fireplace when the furnace is on by:

> Lowering the thermostat setting to 50-55° F. Some warmed air will still be lost, but the furnace won't have to use as much fuel to heat the rest of the house to these temperatures as it would to raise the heat to 65° F.
>
> Closing all doors and warm air ducts entering the room with the fireplace,

and opening a window near the fireplace about 1/2 to 1 inch. Air needed by the fire will be provided through the open window, and the amount of heated air drawn from the rest of the house will be reduced.

If using a simple, open masonry fireplace, consider installing a glass screen. This will cut down on the loss of warmed air through the flue.

When using the heat . . .

Lower the thermostat to 65 degrees during the day and 55 degrees at night. This can save about 3% on fuel costs for every degree in the average temperature in the home. In addition, about 1% on the heating bill can be saved for every degree dialed down only at night.

Keep windows near the thermostat tightly closed, otherwise the furnace will be working after the rest of the room has reached a comfortable temperature.

Have an oil furnace serviced at least once a year, preferably each summer to take advantage of off-season rates. This simple precaution could save 10% in fuel consumption.

Check the duct work for air leaks about once a year if you have a forced-air heating system. To do this, feel around the duct joints for escaping air, when the fan is on.

Relatively small leaks can be repaired simply by covering holes or cracks with duct tape. More stubborn problems may require caulking as well as taping. Almost 9% in heating fuel costs could be saved this way.

If using oil heat, check to see if the firing rate is correct. Chances are it isn't. A recent survey found that 97% of oil furnaces checked were overfired.

If the oil furnace doesn't run almost constantly on a very cold day, call a service person.

Don't let cold air seep in through the attic access door. Check the door to make sure it is well insulated and weatherstripped, otherwise, fuel will be wasted heating that cool air.

Dust or vacuum radiator surfaces frequently. Dust and grime impede the flow of heat. If the radiators need painting, use flat paint, preferably black (it radiates heat better than glossy).

Keep draperies and shades open in sunny windows; close them at night.

For comfort in cooler indoor temperatures, use the best insulation of all - warm clothing.

The human body gives off heat - about 390 Btu per hour for a man, 330 for a woman. Dressing wisely can help one retain natural heat.

Wear closely woven fabrics. They add at least a half a degree in warmth.

For women - slacks are at least a degree warmer than skirts.

For men and women - a light, long-sleeved sweater equals almost 2 degrees in added warmth; a heavy, long-sleeved sweater adds about 3.7°; and two lightweight sweaters add about 5 degrees in warmth, because the air between them serves as insulation to keep in more body heat.

If every household in the United States lowered its average heating temperatures 6 degrees over a 24-hour period, more than 570,000 barrels of oil per day (or more than 3.5% of current oil imports) could be saved.

COOLING AND DEHUMIDIFYING

There are several types of air-conditioning systems for cooling the home during the hot summer months: a wide range of window air conditioners, central air conditioners, or heat pumps. All of these systems work in essentially the same way, and all of them require similar maintenance to keep them working at top efficiency.

Most homes built today have the capability of easy conversion to central air conditioning, if they do not already have it. Homes built with heat pumps to provide heat during the winter, also use the same unit to provide cooling during the summer. Most room air-conditioners are used today where only one or two rooms are to be cooled, or where central air conditioning is impractical or unnecessary. Thus, the type of air conditioning one has or wants depends on the cooling needs and the cost of installing a particular system.

Air Conditioning Components

An air conditioner cools air much as a regrigerator cools the air inside it. The principal difference is that an air conditioner is designed to have the cooled air blown through the cooling coil and out (through whatever distribution system is used) into the house . . . then back (through return-air system) to the coil for recooling. While cooling the air, the coil condenses the moisture carried by the air, and the resulting water runs off through a water line to leave the air less humid.

Whatever type the air conditioner, it will have the functional parts illustrated in Figure 3-22, which appears on the following page. A blower-coil or a self-contained unit has, in addition, an electric-motor-driven blower to circulate house air through the cooling coil. The refrigerant, which circulates from cooling coil to compressor to condenser, and back to the coil, is a volatile liquid (such as Freon) which changes from gas to liquid and back to gas as the pressure and temperature to which it is subjected changes.

Gas (at low pressure) moves from the coil to the compressor, where it is compressed and forced on to the condenser in the form of a hot gas or vapor. Here the hot gas is cooled (by outside air) and becomes a liquid. This liquid, still under pressure, travels to the cooling coil where it is allowed to expand (pressure is relieved) into a gas again. While expanding, it absorbs heat to keep the coil relatively cold . . . and thereby cools the house air blown through this coil. A thermostat can be used to control compressor operation and/or blower operation, to maintain desired house air cooling.

Types of Air Conditioners

Room Air Conditioners: A room air conditioner can be installed either in a window or through a wall. There are many different models, designs, and styles available - ranging in size from small units able to cool just one room, to large units used to cool three or four rooms. Large units are often mounted through the wall and become permanent installations.

AIR CONDITIONING SYSTEM

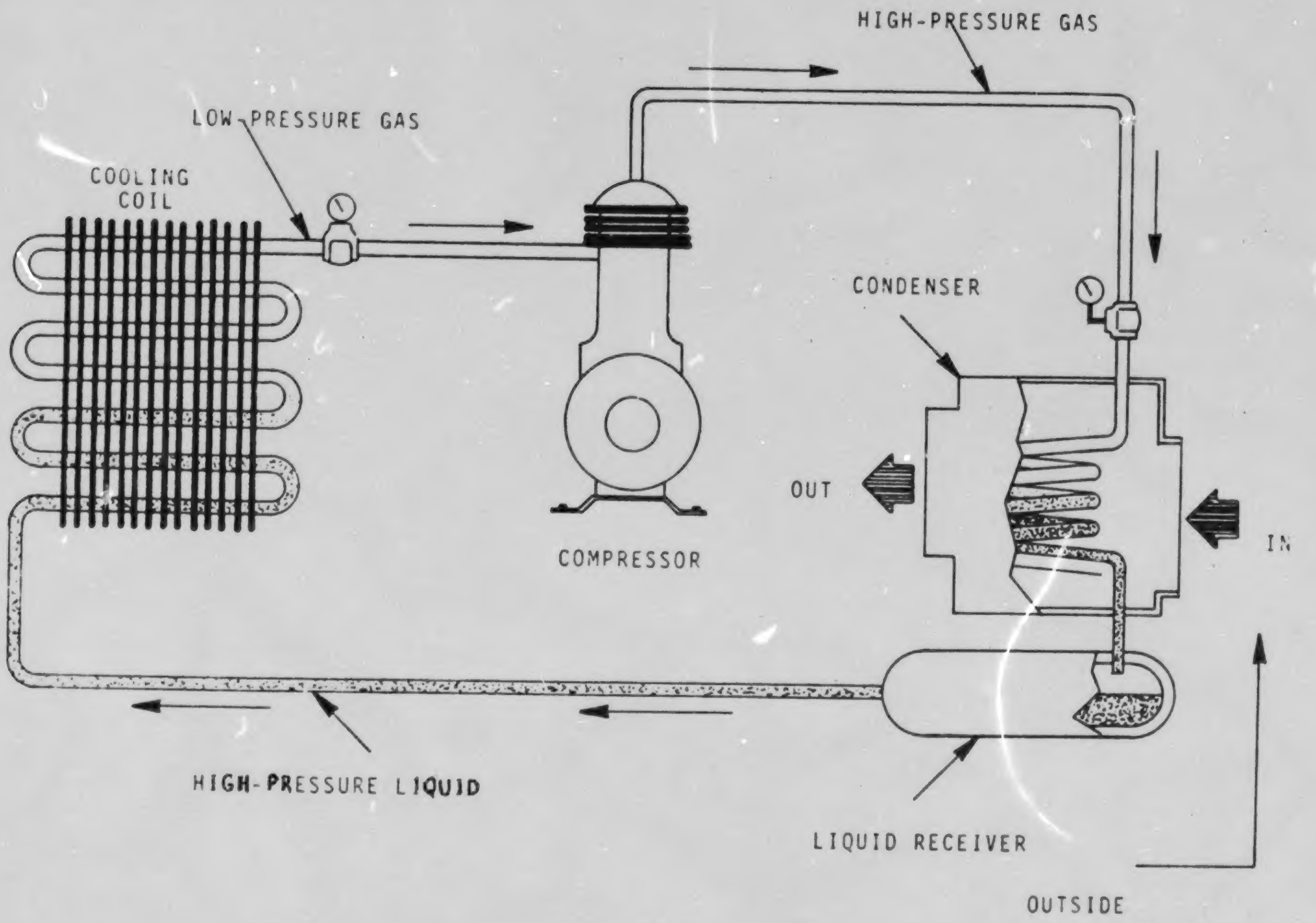

HIGH-PRESSURE GAS
LOW-PRESSURE GAS
COOLING COIL
CONDENSER
OUT
IN
COMPRESSOR
HIGH-PRESSURE LIQUID
LIQUID RECEIVER
OUTSIDE

Figure 3-22.

The wide selection of air conditioners introduces a lot of problems. First, one must check the power consumption outlets, and voltages required by the various air conditioners. Then one must be concerned about the cooling capacity of the air conditioner to insure that it meets particular needs.

One of the biggest reasons an air conditioner does not perform to expectations is that the unit is simply too small for the area being cooled. The opposite problem, or course, occurs when a person buys an extra-large air conditioner, one that has much more cooling capacity than is needed. A large unit makes too much noise, produces drafts, cools the room too quickly, or does not seem to be able to lower the humidity of the air. All of these are common problems with oversized air conditioners, proving that bigger is not always better.

A large number of people buy a room air conditioner with the idea of cooling more than one room. The problem here may be improper air circulation. Cold air is heavy and difficult to move - it has a tendency to sink next to walls and lie on the floor. A room unit can provide only limited air circulation. It has a fan to blow the air out into the room, but it has no way really to circulate the air through the house. Cool air will not circulate by itself as readily as warm air, so you have to be sure that either the air conditioner's fan is able to blow the cool air into all rooms or provide an extra fan to assist.

If the air conditioner is installed in a room that has limited circulation to other rooms - like a bedroom - the room with the air conditioner will be much cooler than the other rooms. Using fans to help circulate the cool air can bring the air conditioner's performance up to what it should be. Fans are beneficial in another way, for the air circulating from the fans will speed up evaporation from the body and make one feel cooler, It will probably be possible to turn the thermostat on the air conditioner to a warmer setting and save some electricity by using a fan.

The performance of a room air conditioner depends a good deal on the place where it is installed. For example, if the unit is installed in a window directly opposite a door, the fan on the air conditioner is going to blow cool air out each time the door is opened. Certainly, this does not conserve energy or cool a room efficiently.

If a person wants to cool two or more rooms, it is desirable to locate the air-conditioner opposite an open doorway to one of the rooms. If there is no window opposite the doorway, install the air conditioner in the wall. Also, use the directional vents or louvers on the air conditioner to throw the air toward the open doorway. Not all air conditioners have movable louvers and not all movable louvers work very well, so be careful when buying an air-conditioner.

The condenser (the part of the room air conditioner that extends outside the house) must have good air circulation around it. The condenser is the part of the air conditioner that releases the absorbed inside heat into the surrounding outside air. If there is not good air circulation around the condenser, the heat cannot be carried away, and the efficiency of the air conditioner is reduced. The condenser should not be placed in direct sunlight, since the sunlight warms the condenser and makes it more difficult to disperse the heat.

Sometimes an air conditioner is installed in a wall, with the condenser extending into a garage. This is not recommended, since it can create problems with both heat and air circulation. If the garage door is left closed, circulation over the condenser is reduced, and the heat from the condenser is dispersed into the garage, raising the temperature inside the garage. Unless the garage door is left open when the air conditioner is operating, the efficiency of the air conditioner will be reduced considerably.

When the condenser extends outside the house, try to avoid locations that shelter the condenser from natural wind currents. While the air conditioner does have an external fan to circulate air through the condenser, it helps to have fresh air available for good cooling. In general, the cooler the air around the condenser, the more efficiently the air conditioner will perform.

Size also is very important. If an air conditioner is too small, the compressor will run continuously on hot days and still not cool the room. Conversely, if the unit is too large, the compressor will start up and cool the area so quickly that it will run only a short time. Given the large amounts of electricity needed to start an electric motor and bring the air conditioner up to normal operation, the more often the compressor motor must start, so more electricity will be wasted. Another result of short operation times is that the humidity in the room will not be lowered as much, and this means the thermostat has to be set to a lower temperature for comfort, wasting more electricity.

Window air conditioners are sized in three ratings: horsepower, Btu, and tons of refrigeration (12,000 Btu is equal to one ton of refrigeration). A one-horsepower unit provides about 8,000 Btu, depending on the efficiency of the unit.

An average-size room with good insulation will usually require a unit rated at 8,000 Btu, or 3/4 ton. A one-ton air conditioner is usually large enough to cool two rooms, while a two-ton air conditioner will usually cool four or five rooms. These estimates depend, of course, on the air circulation in the house, its construction, insulation, and location.

Central Air Conditioning Systems: A central air conditioning system operates the same as a room air conditioner, with similar components and operation. A unit merely has larger parts and capacity, and is designed to cool an entire house instead of one or a few rooms.

The evaporator coil is uaually cased in the furnace component. The condenser is outside the house, connected to the evaporator by copper tubing carrying the refrigerant back and forth. An alternate type is in one unit located outside the house and connected to the furnace duct system through a separate duct line.

Maintenance and Use

The efficiency with which an air conditioner can dehumidify the air depends primarily upon how cold the evaporator coil gets. If the fan of the air conditioner is set at a low speed, the coil will get colder and more moisture will be removed from the air; however, the air conditioner may not be able to cool the house enough on especially hot days. At high fan speeds, the air conditioner will be able to cool better, but it will not be able to dehumidify as well. For best comfort, it is more efficient to use a low fan setting for humid days, and a high fan setting on hot days.

Constantly adjusting the thermostat up and down does no good. An air conditioner will not cool a room any faster if the thermostat is set to a much cooler setting when it is first turned on. The compressor turns on when the thermostat senses that the room is too warm, and does not turn off until the room temperature reaches the setting on the thermostat. The fastest way to cool a room is to set the fan speed on high. This will make the air conditioner work at maximum capacity. Set the thermostat at a comfortable temperature, then leave it alone, except for minor changes to take care of cool or hot days. In general, an air conditioner with several fan speeds will permit the room to be kept at a more uniform temperature, without having to adjust the thermostat as much.

Should one open up the house during the day when not at home? This is not a good idea, if one lives in a climate with humid summers. If the house is closed during the day, the temperature may increase, but the humidity will not - it will decrease. The temperature inside a sealed home will not become much hotter than the outside temperature. This will permit the air conditioner to cool faster, and it will save electricity as well. As a general rule, if the humidity of the outside air is more than 30%, it will be more economical to close up the house when leaving in the morning. The inside temperature may get as hot as the outdoors, but the lower humidity inside makes the home feel much cooler.

There are many things one can do to keep the air conditioning operating at peak efficiency. An air conditioner has filters that get clogged with dust; finned coils that become dirty; and motors that need lubricating. These simple tasks are not difficult to do and require only a wrench and a couple of screwdrivers.

All air conditioners should be lubricated and cleaned each year. The best time for doing this is a month or so before the summer cooling season begins.

As room air is drawn into the air conditioner, it first passes through a foam or aluminum mesh filter much like the air filters in many furnaces. The air filters are cleanable, and they should be cleaned several times a year.

The evaporator coil at the front of the air conditioner rarely needs attention; the cleaning action of water condensing on it usually does a good job of keeping it free of dirt. However, one should routinely inspect this coil whenever cleaning the air filter. If the air filter has moved or allowed much dirt to pass through, sections of the evaporator coil may require some cleaning. After several years of use, some sections of the coil are bound to accumulate dirt.

If the thermostat on an air conditioner is set at a very low temperature, the evaporator coil may begin to collect ice. What happens is that the temperature of the evaporator drops below the freezing point and ice begins to form on the evaporator. Ice usually starts to form along the refrigerant inlet at the top of the coil, and it gradually progresses downward, until the whole coil is blocked with ice. Since the formation of ice restricts the flow of air through the evaporator coil, the more ice that forms, the colder the coil will get, and this causes even more ice to form.

The common reason for the evaporator icing up is that the thermostat is set at too low a temperature. When the thermostat is set properly, the room will stay at a fairly comfortable and uniform temperature.

The moisture that collects on the evaporator drains back to a pan under the condenser coil. There, a ring on the fan blade often picks up the water and slings it onto the condenser. This technique increases the efficiency of the air conditioner, because the evaporating water helps cool the condenser coil.

The condenser collects much more dirt than the evaporator. At most, a wire screen is used to keep out leaves and other large objects, but this still lets plenty of dirt and trash through to the condenser. To do a good cleaning job, remove the air conditioner case so it is possible to get at all the inside parts.

Air conditioners normally have two motors: one for the fan, and the other for the compressor. In this way, the fan motor can run constantly to circulate air in the room, while the compressor motor need only run when the thermostat calls for more cooling. The fan motor may be single- or double- shafted, depending on how the fan blades are connected to the motor. The most usual arrangement is the double-shafted motor, in which the shaft extends from each end of the motor. A large fan blade is connected to one shaft of the motor, to circulate air over the outside condenser coil. The other end of the shaft extends through a panel to a squirrel-cage fan that circulates air over the evaporator coil and into the room. The advantage in using a squrrel-cage fan on the inside is that it is much quieter in operation.

During the yearly tuneup, clean the fan motor and fan blades (particularly the condenser fan blades). The fan motor should also be oiled, though some of the newer fans have sealed bearings that do not require oiling every year.

Once a year, clean out the parts of a central air conditioner, the same as for a room air conditioner. The air filter should be cleaned or replaced about once a month. When the evaporator coil is located in the coil case of the furnace, the central air conditioner uses the furnace fan, so this fan will require more frequent inspection and cleaning. With the alternate, single-unit system, the central air conditioner contains a separate fan to force cool air into the furnace duct system. Electrically heated homes may use this alternate system with duct work, just for air conditioning.

Grass, leaves, and dirt may collect in the condensing unit located outside the house. Be sure to remove any restrictions that could reduct the efficiency of the unit, or impair its operation.

Dehumidifying

Summer discomfort is largely caused by high humidity. The excess water content of the air prevents sweat from evaporating, and thus diminishes the body's natural cooling effect.

Removing excess water from the air in homes is possible without resorting to the expense of air conditioning. A dehumidifier is an apparatus that draws room air over a cooling coil, where it loses moisture. Water is removed by condensation on cold coils. It is then heated slightly and returned by fan.

When shopping for a unit, look for the water removal capacity rating of the Association of Home Appliances Manufacturers. Humidifiers can range in price from $90 (with a water removal capacity of eleven pints a day) to $150 (with a 30-pint removal capacity, and convenience features). The electrical operating rate can change from $.20 to $.50 per day. Operating costs are reduced when an area has been sufficiently dried and the machine does not have to run steadily.

For Safe, Efficient Operation -

Read the owner's manual.

Place the unit at least 6 inches (15 cm) from the nearest wall for free air flow.

Close all doors and windows in the area to be dried.

For the first few days, turn the humidistat to "Drier" or "Extra Dry".

Turn the machine OFF and disconnect power cord before emptying the water pans; be sure the area and unit are dry before reconnecting cord.

On cool days, check the cold coils for frosting; if frosting occurs, turn OFF the unit until melted.

Always unplug the cord before cleaning the unit; dust the grills and wipe the cabinet.

Every few weeks, clean the inside of the water container with a soft cloth and a mild detergent to prevent mold, mildew, and bacteria.

Once a month, dust the lint from the cold coils.

Solar Cooling

Of the three general categories of space cooling methods for residential building - refrigeration, evaporative cooling, and radiative cooling - solar energy is only directly useful in refrigeration methods. Refrigeration systems cool by removing heat as it comes in contact with a cool, refrigerating surface. In both the conventional vapor-compression systems using electric motors and heat pumps, and the absorption systems which use a fuel, solar heat could be used to drive the compressor in vapor-compression systems, or replace the fuel in absorption systems.

Vapor-Compression Cooling: In the familiar vapor-compression cycle (see Figure 3-23 on the following page), an electric motor drives a compressor that "pumps" refrigerant gas from the relatively low pressure and temperature in the evaporator up to the pressure and temperature level existing in the condenser.

Absorption Cooling: In mechanical cooling, unwanted heat is absorbed at low pressure and temperature, and then rejected at a higher, more convenient pressure and temperature.

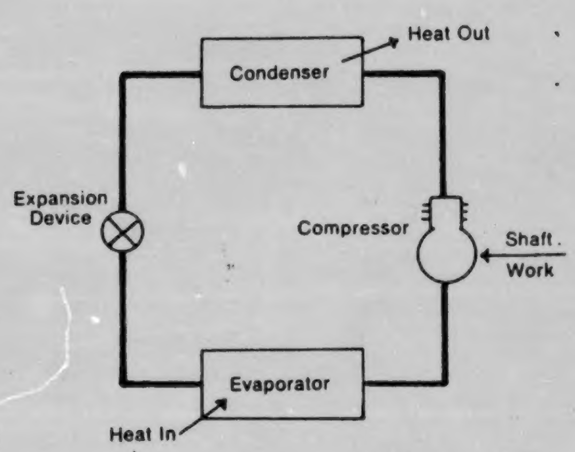

Condenser
Heat Out
Expansion Device
Compressor
Shaft Work
Evaporator
Heat In

Figure 3-23: Basic vapor compression refrigeration cycle.

In the absorption process (see Figure 3-24), heat replaces horsepower. The compressor is replaced by an absorber-generator assembly, in which a liquid is used to carry the refrigerant vapor from evaporator to condenser.

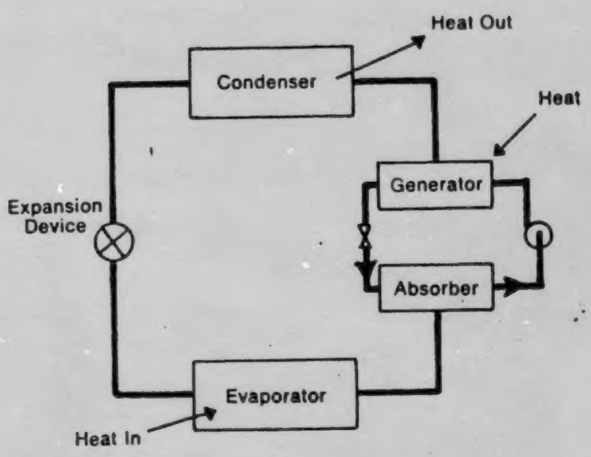

Heat Out
Condenser
Heat
Generator
Expansion Device
Absorber
Evaporator
Heat In

Figure 3-24: Generator-Absorber replaces mechanical compressor.

A closer look at the absorber-generator (see Figure 3-25), shows how refrigerant vapor from the evaporator enters the absorber, where the vapor is absorbed by a liquid. The liquid solution is then pumped to the generator (which is at the same pressure as the condenser).

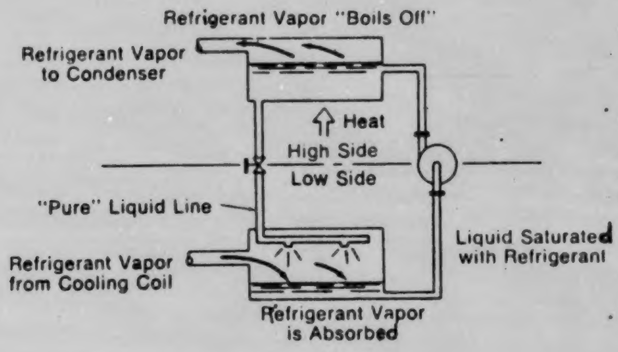

Refrigerant Vapor "Boils Off"
Refrigerant Vapor to Condenser
Heat
High Side
Low Side
"Pure" Liquid Line
Liquid Saturated with Refrigerant
Refrigerant Vapor from Cooling Coil
Refrigerant Vapor is Absorbed

Figure 3-25: Absorber-Generator Details

In the generator, the liquid is heated. This drives the refrigerant vapor out of solution and the gas continues on to the condenser. The liquid, now free of refrigerant, is returned to the absorber to repeat the process.

In conventional absorption cooling units, heat is supplied from gas or oil. In a solar-assisted unit, a hot fluid provides the required heat (see Fig. 3-26).

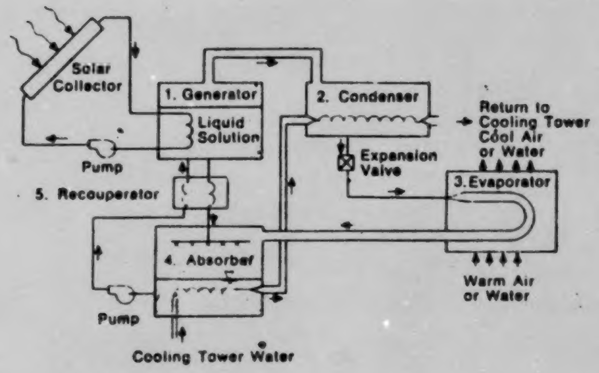

Solar Collector
1. Generator
Liquid Solution
2. Condenser
Return to Cooling Tower
Cool Air or Water
Pump
Expansion Valve
3. Evaporator
5. Recouperator
4. Absorber
Warm Air or Water
Pump
Cooling Tower Water

Figure 3-26: Solar Powered Absorption Air Conditioner.

Lithium-Bromide Chillers: Of the absorption refrigeration currently in use, the Lithium-Bromide Chillers appear to hold the most promise. Water is the refrigerant, lithium-bromide is the absorbent. The system operates under vacuum and requires a cooling tower for water-cooled condensing. The system cannot use air-cooled condensing because of the low temperature in the absorber.

There are two types of chillers - air chillers and water chillers - which also describes their chilling function. With the air chiller, room air is circulated directly past the evaporator coils.

The water chiller requires a remote fan coil unit with room air cooled as it passes through the unit. The water chiller has an advantage over the air chiller in that it is possible to store chilled water when the building does not require cooling (as in the morning or at night). This enables the system to provide for a large peak cooling capacity. Typical requirements to provide 36,000 btu/h of cooling, and a hot water supply of eleven (11) gallons per minute at 190° F. Cooling capacity obviously falls off drastically with lower temperature water supply from the collector circuit.

Evaporative Cooling Plus Storage: Conventional evaporative cooling in arid and semi-arid parts of North America is accomplished by circulating outdoor air through a wetted pad. This simultaneously lowers the dry bulb temperature of the air and raises the wet bulb temperature. This cool but humid air is then circulated through the house for comfort cooling.

Strictly speaking, evaporative cooling cannot be "helped" or powered by a solar system. However, the rock (pebble) bed storage associated with an all-air solar heating system can be used along with an evaporative cooler to store cold at night for use during the day (see Figure 3-27, on the following page).

Here is how it works. At night, outdoor air is circulated through the evaporative cooler and the air is then circulated through the rock storage to subcool the rocks. This moist air is then exhausted to the out-of-doors.

In the daytime, hot room air is routed through the cool pebble-bed, sensible heat is removed and circulated throughout the house. Note that no latent heat (moisture) is removed in this process, thus, this technique is not well suited for all areas.

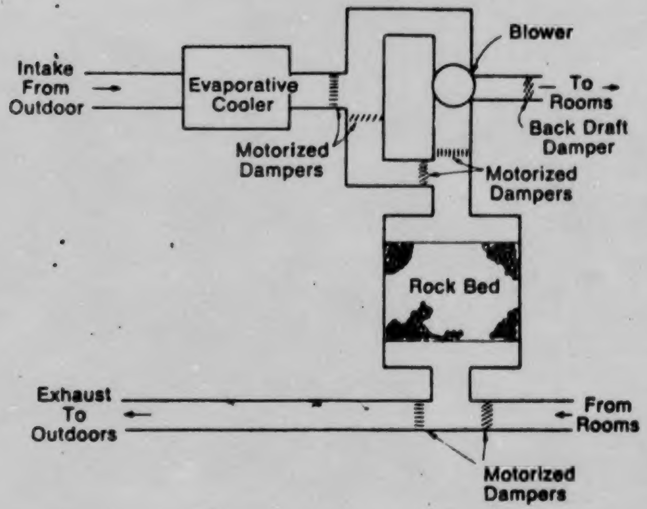

Intake From Outdoor
Evaporative Cooler
Motorized Dampers
Blower
To Rooms
Back Draft Damper
Motorized Dampers
Rock Bed
Exhaust To Outdoors
From Rooms
Motorized Dampers

Figure 3-27: Evaporative Cooling With Rock Storage

Other Cooling Possibilities: Besides providing comfort cooling via mechanical devices, it is also possible to cool using chemical reaction devices similar in operation to the widely used chemical dehumidifiers - liquid absorption and solid absorbent equipment.

In these devices, a desiccant - moisture capturing chemical - is used to dehumidify air and then solar heat is used to provide some of the energy to regenerate the desiccant after it becomes saturated with moisture. Evaporative cooling can also be added.

One innovative device under study is the Munter Environment Control (MEC) unit shown in some detail in Figure 3-28, which appears on the following page.

Reverse radiation from the absorber surface of a flat-plate collector to the cold night sky can cool the absorber surface. It can also cool the water or air circulating through a collector. To use this principle, a shallow water pond covers the roof with sectionalized, retracting, insulated covers over the pond. At night, the covers are retracted to cool the water in the pond by both

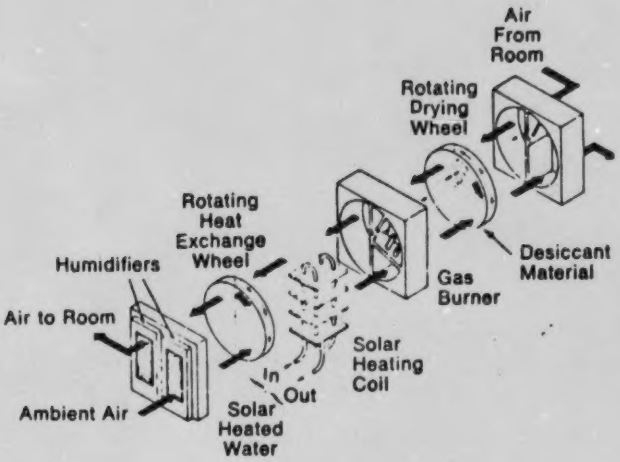

Air
From
Room
Rotating
Drying
Wheel
Rotating
Heat
Exchange
Wheel
Humidifiers
Desiccant
Material
Gas
Burner
Air to Room
Solar
Heating
Coil
In
Out
Ambient Air
Solar
Heated
Water

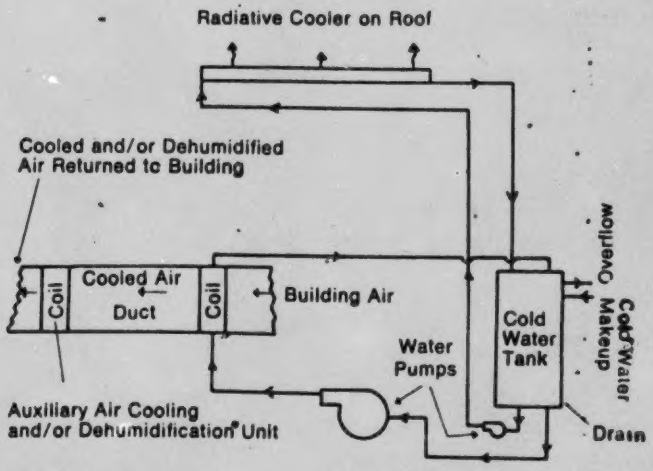
Figure 3-28: Schematic of Adsorption Cycle
(courtesy of the Institute of Gas Technology).

evaporation and radiation. They are then closed during the day to prevent the water from being heated. The cool water is circulated through fan-coil units to cool the rooms below. In the winter, the process is reversed to capture the sun's warmth during the day. The covers are closed at night to retain the heat which is radiated to the rooms below.

Evaporation of the water, which occurs naturally, increases its salinity and thus required periodic draining. Possible freezing is a problem.

The generalized schematic (Figure 3-29) provides an idea for this type system.

Figure 3-29: Radiative Cooling System


Radiative Cooler on Roof
Cooled and/or Dehumidified
Air Returned to Building
Coil
Cooled Air
Duct
Coil
Building Air
Overflow
Cold Water
Makeup
Cold
Water
Tank
Water
Pumps
Auxiliary Air Cooling
and/or Dehumidification Unit
Drain

Energy Conservation

The following tips for cooling energy savers are from the U. S. Department of Energy and serve as a convenient summary for the points discussed in relation to cooling and dehumidifying.

Overcooling is expensive and wastes energy. Don't use or buy more cooling equipment capacity than is actually needed.

If central air-conditioning is needed, select the smallest and least powerful system that will cool the home adequately. A unit larger than needed not only costs more, but probably won't remove enough moisture from the air.

Ask the dealer to help determine how much cooling power is needed for the space to be cooled and for the local climate. (For further information, see page 5, Energy Efficiency Ratios.)

Make sure the ducts in the air-conditioning system are properly insulated, especially those that pass through the attic or other uncooled spaces. This could save almost 9% in cooling costs.

If central cooling is not needed, consider using individual window or through-the-wall units in rooms that need cooling from time to time. Select the smallest and least powerful units for the rooms to be cooled. As a rule, these will cost less to buy and less to operate.

Install a whole-house ventilating fan in the attic or in an upstairs window to cool the house when it's cool outside, even if there is a central unit.

It will pay to use a fan rather than mechanical cooling when the outside temperature is below 82° F. When windows are open, the fan will pull cool air through the house and exhaust warm air through the attic.

When using air conditioning . . .

Set the thermostat at 78° F, a reasonably comfortable and energy-efficient indoor temperature.

The higher the setting and the less difference between indoor and outdoor temperature, the less outdoor hot air will flow into the building.

If the 78° F setting raises the temperature 6 degrees (from 72° F to 78° F, for example), between 12 and 47% can be saved in cooling costs, depending on location of the house.

Don't set the thermostat at a colder setting than normal when turning the air-conditioner ON. It will NOT cool faster; it WILL cool to a lower temperature than needed and will use more energy.

Set the fan speed on HIGH except in very humid weather. When it's humid, set the fan speed at low; there will be less cooling, but more moisture will be removed from the air.

Clean or replace filters at least once a month. When the filter is dirty, the fan has to move longer to move the same amount of air, and this takes more electricity.

Turn off window air conditioners when leaving a room for several hours. Less energy will be used cooling the room later than if the unit is left running.

Consider using a fan with window air conditioner to spread the cooled air farther without greatly increasing your power use; but be sure the air conditioner is strong enough to help cool the additional space.

Never place lamps or TV sets near the thermostat. Heat from these appliances is sensed by the thermostat and could cause the air conditioner to run longer than necessary.

With or without cooling . . .

Keep out daytime sun by placing vertical louvers or awnings on the outside of windows, or draw draperies, blinds, and shades indoors. Heat gain from the sun can be reduced by as much as 80% this easy way.

Keep lights low or OFF when possible. Electric lights generate heat and add to the cooling load.

Do cooking and use other heat-generating appliances in the early morning and late evening hours, whenever possible.

Open the windows instead of using the air conditioner or electric fan on cooler days and during cooler hours.

Turn OFF the furnace pilot light in summer, but be sure it's reignited before turning the furnace ON again.

Dress for the warmer indoor temperatures. Neat but casual clothes of lightweight, open-weave fabrics are most comfortable.

A woman will feel cooler in a lightweight skirt instead of slacks. A man will feel cooler in a short-sleeved shirt than in a long-sleeved shirt of the same weight fabric.

Without air conditioning . . .

Be sure to keep windows and outside doors closed during the hottest hours of the day.

Use windows or whole-house ventilation fans to cool the house, when it's cool outside.

Use vents and exhaust fans to pull heat and moisture from the attic, kitchen and laundry directly to the outside.

If every household in the United States raised air conditioning temperatures by 6 degrees, the equivalent of 36-billion kilowatt-hours of electricity could be saved in one year.

HEAT PUMPS

A heat pump is the most efficient type of mechanical heating system. A heat pump does not have to burn fuel to produce heat, and it does not have to waste electrical energy by running it through a resistive wire element to produce heat. The heat pump only requires enough electricity to run a compressor motor, which takes the heat out of the air on the outside of the house and deposits this heat inside the house.

The heat pump is actually a kind of refrigeration or air-conditioning system that can work in reverse. In summer, the heat pump cools the house in the usual manner, removing heat from within the house and depositing it outside. In winter, the heat pump works in reverse, removing heat from the outside and depositing it inside. (See Figure 3-30 on the following page.)

Taken on a year-round basis, a heat pump can usually heat a house for one-third to one-half the cost of conventional electric heat. In a northern city like Cleveland, Ohio, for example, the annual heating cost for a heat pump is about 50% of that for an ordinary electric furnace, making the heat pump cost-competitive with natural gas in that area. In southern states, operating efficiency is much higher because outside temperatures are higher.

Heat pumps cost substantially more to purchase and install than conventional heating systems with central cooling. Manufacturers and representatives claim, however, that the heat pump can greatly reduce the heating bill, so it would not take long to make up the differences in the original purchase prices. Keep in mind, however, that location has a lot to do with the cost savings. As long as the winter temperature in an area stays high enough, the heat pump will save quite a bit on a heating bill. As temperatures drop, so do the savings. At lower temperatures, the electric resistance heat is turned on automatically, to assist the heat pump.

Energy Efficiency

The efficiency of a heat pump is measured in terms of how much easier it is to pump heat energy than to generate it by conventional means. When used to heat a house, the efficiency of a heat pump depends primarily on how cold it is inside. As the temperature drops, the efficiency also drops.

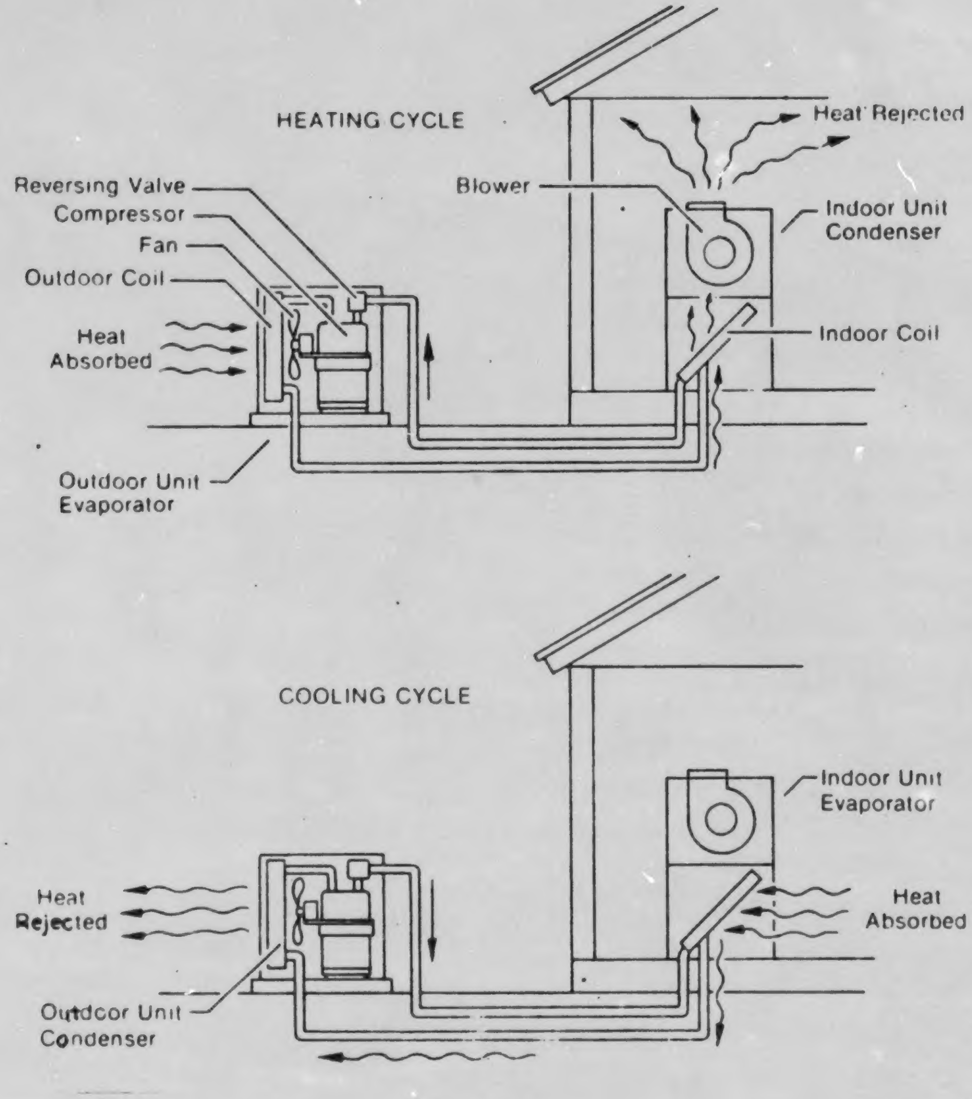

HEATING CYCLE
Heat Rejected
Reversing Valve
Compressor
Fan
Outdoor Coil
Heat Absorbed
Blower
Indoor Unit Condenser
Indoor Coil
Outdoor Unit Evaporator
COOLING CYCLE
Indoor Unit Evaporator
Heat Rejected
Heat Absorbed
Outdoor Unit Condenser

Figure 3-30: Heat Pump System

If it gets too cold outside, the heat pump automatically switches an electric heating element to ON, when it becomes easier and more economical to generate heat energy that way. Normally, though, as long as the outside temperature is above about 20° F, the heat pump can heat the house more cheaply than an electric furnace. As the outside temperature approaches the inside room temperature, the efficiency continues to climb dramatically.

Consideration of how the Energy Balance principle applies to the heat pump will show how it may provide heating with a relatively small expenditure of energy. Referring to Figure 3-31, the total energy into the system equals the total energy out:

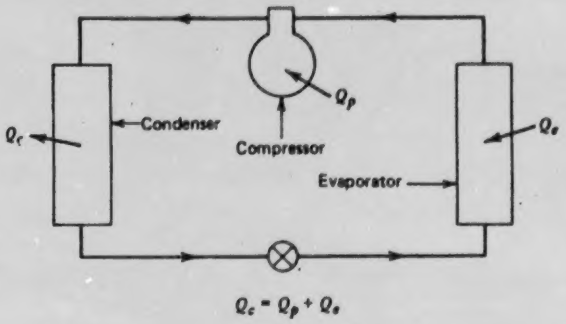


Figure 3-31.

$$Q_c = Q_p + Q_e$$

where:

Q_c is the heat rejected from the condenser;

Q_p is the heat equivalent of compressor power input;

Q_e is the heat absorbed in the evaporator

The significance of this equation is that the useful heating, Q_c, is greater than the energy needed to drive the compressor, Q_p, by the amount Q_e, which does not require any energy expenditure. Contrast this with any direct heating system, electrical or by burning a fuel to generate steam or hot water. In these cases, of course, the energy expended is at least equal to the useful heating. A relative measure of the performance of the heat pump is the heating coefficient of performance, defined as:

$$COP_h = \frac{Q_c}{Q_p} = \frac{\text{heat rejected from condenser}}{\text{heat equivalent of compressor power}}$$

Note that the coefficient of performance of a heat pump does not have the same meaning as when the unit is used for refrigeration. The heat pump COP_h is useful in illustrating the advantage of heating by using electrical energy to drive a heat pump compressor rather than using the electricity directly in resistance heaters.

Solar Assisted Heat Pump

An effective use of the heat pump is in combination with solar energy. The coefficient of performance decreases with a decrease in evaporator temperature. With the conventional application of the heat pump, this temperature is lower than ambient air temperature, which results in a low COP in winter. However, a solar energy collector can be used to supply water at a much higher temperature than normally available in winter for the evaporator, say, 75-100° F. This moderate temperature can be achieved with a relatively inexpensive collector, and will result in a low heat pump energy use. This arrangement is called the solar assisted heat pump.

The installation of a heat pump with a solar heating system introduces several interesting possibilities. The simplest installation would be to use a conventional automatic heat pump as the auxiliary heat in a hydronic system. This is shown in Figure 3-32, which appears on the following page.

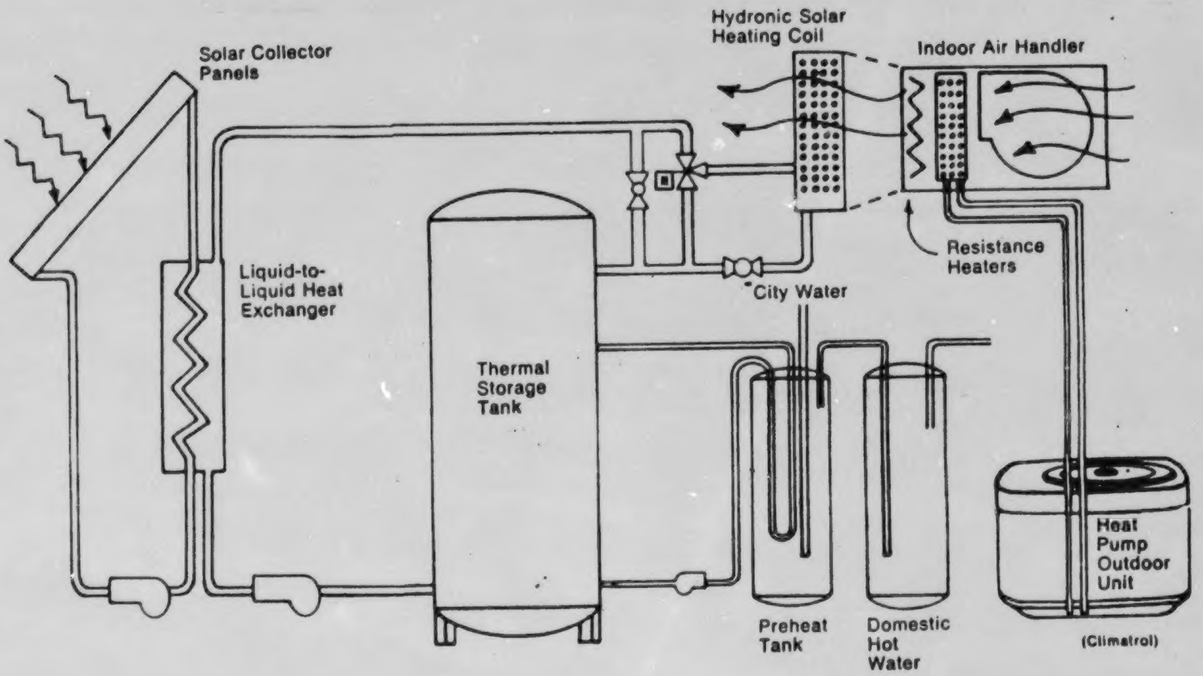
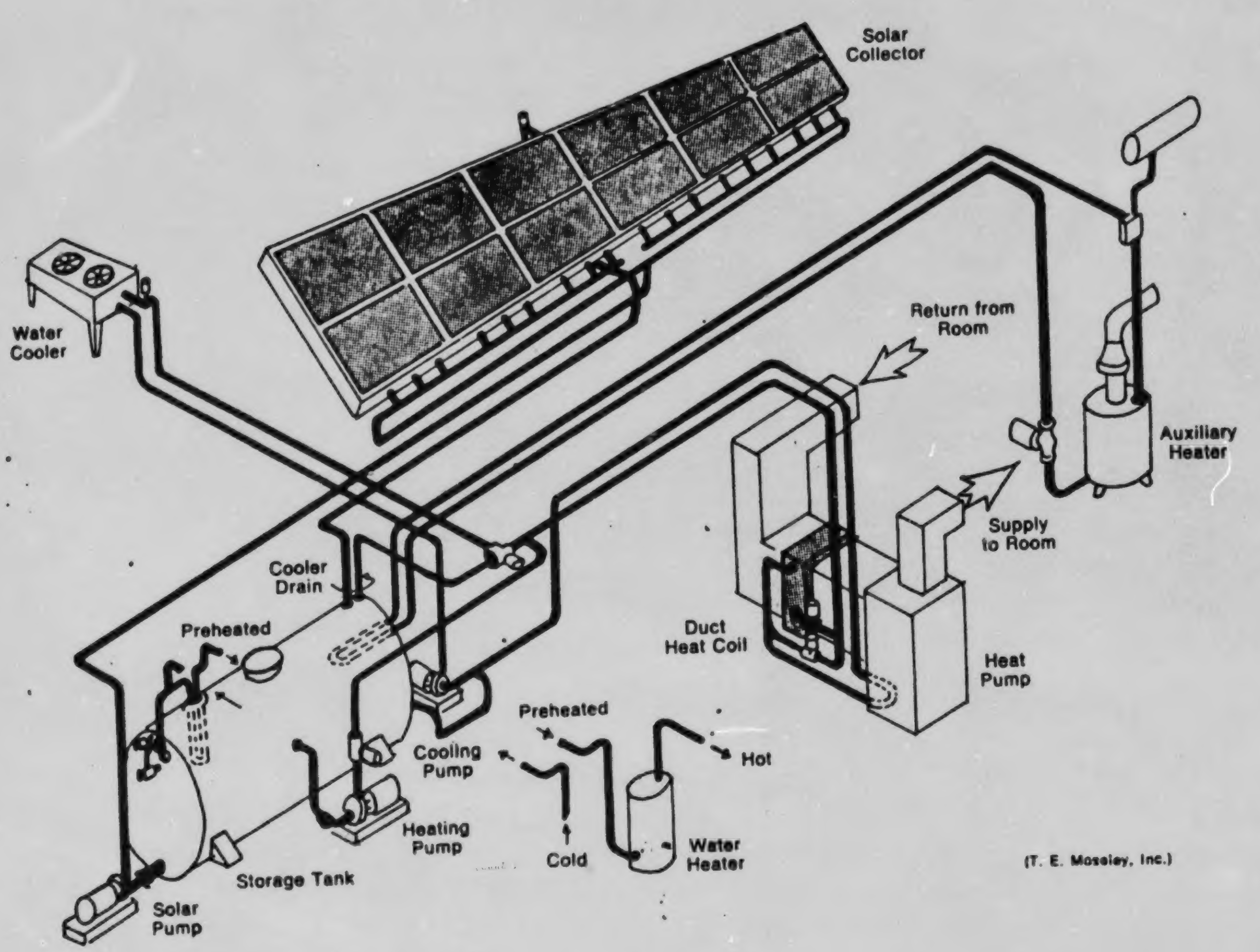

Solar Collector Panels
Hydronic Solar Heating Coil
Indoor Air Handler
Resistance Heaters
Liquid-to-Liquid Heat Exchanger
City Water
Thermal Storage Tank
Heat Pump Outdoor Unit
Preheat Tank
Domestic Hot Water
(Climatrol)

Figure 3-32: Air to Heat Pump With Solar Assist

One current arrangement includes these operating modes:

1. In mild weather, solar heated duct coil provides heating.
2. As temperature drops, for example, to 45-50° F, the heat pump supplies heat and the solar unit goes into heat-storing mode.
3. At heat pump balance point, (output of heat pump equals building load), duct coil is supplied heat from storage, to supplement heat pump output.
4. In the event of no solar heat at collectors or in storage, electric resistance heaters are energized to supplement the output of the heat pump.

Another approach is to use a conventional water-to-air heat pump with solar assist. This is shown in Figure 3-33.


Solar Collector
Water Cooler
Return from Room
Auxiliary Heater
Supply to Room
Cooler Drain
Preheated
Duct Heat Coil
Heat Pump
Preheated
Hot
Cooling Pump
Heating Pump
Cold
Water Heater
Storage Tank
Solar Pump

(T. E. Moseley, Inc.)

Figure 3-33: Water to Air Heat Pump With Solar Assist

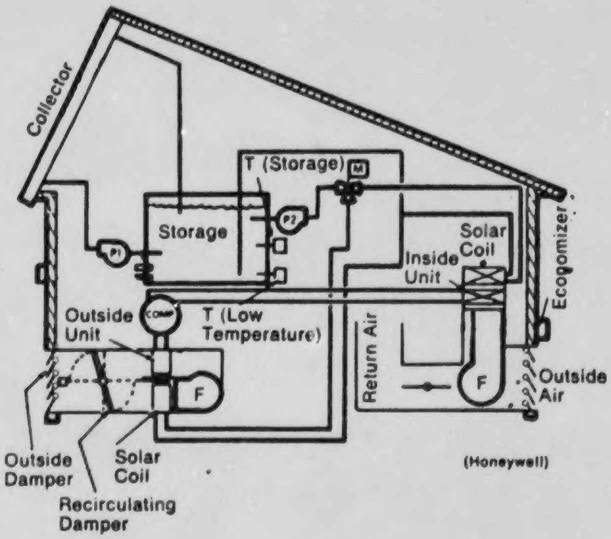
There are three operating modes for this system:

1. Storage water 80° F or above, solar heating through duct coil.
2. Storage water between 80° F and 45° F, heat pump extracts heat from storage, boosts temperature via refrigeration cycle and supplies indoor refrigerant coil placed in duct.

3. If storage temperature falls below 45° F, auxiliary heat raises the temperature of the storage tank to 55° F.

In this case, the use of the water-to-air heat pump permits greater drawdown of storage temperature which, as noted earlier, improves overall collector performance. Whether the improvement is great enought to offset additional operating time and electricity is not yet well established.

A third combination of heat pump and solar heating systems is shown in Figure 3-34. In this instance, a liquid-to-air solar system supports an air-to-air heat pump.


Collector
T (Storage)
M
Storage
P1
P2
Solar Coil
Inside Unit
Ecogomizer
Outside Unit
COMP
T (Low Temperature)
Return Air
F
F
Outside Air
Outside Damper
Solar Coil
Recirculating Damper

(Honeywell)

Figure 3-34: Liquid to Air Solar System Outfitted With An Air-to-Air Heat Pump

The solar system serves two duct coils. One is in the indoor air-handler for direct space heating; the other heats air supplied to the "outdoor" section of the heat pump. Descriptions of the three operating modes follow.

1. Heat Pump Heating with Solar Preheat Assist
    a. room thermostat demands heat
    b. storage temperature too low for direct heat supply to indoor duct coil

c. outside temperature is lower than storage temperature

d. pump from storage and diverting valve supply heat to preheat coil for heat pump outdoor section

As in the water-to-air temperature example of Figure 3-32, this preheating of outdoor air, which is the heat source for the heat pump, raises the coefficient of performance of the heat pump. This permits a greater drawdown of storage temperature, which improves collector performance. Since cold outdoor air moves over this coil, freeze protection may be required.

2. Heat Space Directly From Storage

Whenever storage temperatures exceed the control point, for example, 90° F, heat is pumped directly from storage to duct coil for direct space heating.

3. Heating Space With Heat Pump Only

When outside air temperature is higher than storage temperature, the heat pump operates alone, extracting heat directly from outside air. In any of these modes, if the collector temperature exceeds storage temperature, then the differential controller will start the collector pump and begin charging storage.

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ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

WATER USE AND ENERGY CONSERVATION

STUDENT MATERIAL

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

WATER USE AND ENERGY CONSERVATION

INTRODUCTION

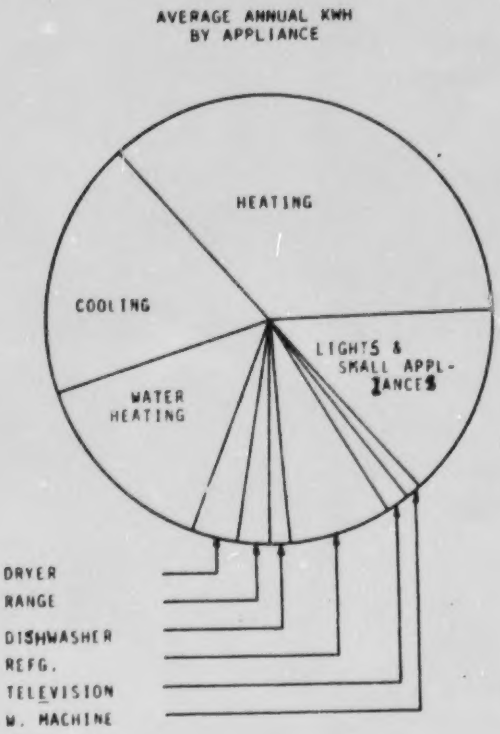
Domestic Water Use: Water has been considered a free resource with unlimited supply and availability in this country. This attitude, however, is changing somewhat. Environmental considerations now restrict the building of dams, water reserves, and sewage plants. Population is shifting more to the Sunbelt states, where water can be relatively scarce. This requires new water supplies as well as energy to treat the water before using, and to pump and transport water for servicing homes and businesses. Therefore, water used in the home represents an expenditure of considerable energy, either directly or indirectly, and should be used conservatively.

The most direct expenditure of energy in water use is for heating water. If a person conserves household water, there will be a small savings realized on the monthly water bill; but if a customer uses less hot water, a substantial savings on the gas or electric bill can be achieved.

Energy used to heat water for domestic use is the second largest household use of gas, electricity, and oil, following space heating and cooling requirements. The cost of heating water constitutes approximately 25% of the annual home energy bill (Figure 4-1, following page). Conservation measures can be taken without sacrificing domestic comfort or convenience, and at minimal expense.

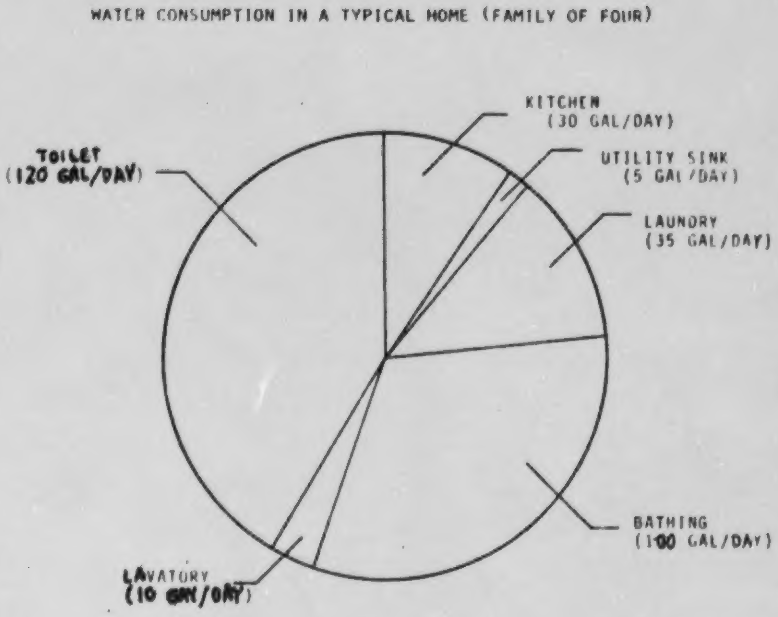
The average American family of four uses approximately 300 gallons of water a day for indoor use. Figure 4-2 (following page) breaks down this water consumption as follows: toilets consume 40%; lavatories, 3%; bathing, 33%; laundry, 12%; utility sink, 2%; and kitchen, 10%.

Of this daily amount, about 75 gallons is heated water. Therefore, of the 110,000 gallons of water used annually, 27,500 gallons are hot, which require 23 to 41 million Btu of energy to heat. This amounts to 180 gallons of oil,



SOURCE: TEXAS POWER & LIGHT COMPANY

Figure 4-1.



SOURCE: EUGENE ECCLI, LOW-COST, ENERGY-EFFICIENT SHELTER FOR THE OWNER AND BUILDER, 1976.

Figure 4-2.

or 6,000 Kwh of electricity annually at a cost to the customer of about $120 for oil or gas, and over $200 for electricity. This cost is above the cost for the water itself, which can be $75 to $100 annually. The actual water consumption for the home varies widely, depending on living habits of the users and the efficiency of fixtures and appliances. To save energy and cut down on hot water costs, consider the heater tank in terms of its size and location.

Water Conservation

Conservation in all forms is the attitude people are taking today. The consumer is aware of the fuel shortage and unnecessary waste of fossil fuels facing the nation today. Most people do not consider water as a resource which is in short supply. In most areas of the country, it is not an endangered resource, and it is a renewable resource. However, in some parts of the South, where hot, dry climates prevail, water can be a precious commodity. Regardless of the shortage of water to the home, treatment plants required to purify the water before it is used and treat it after it is used, and pumping stations to transport it to and from the home require energy. Most municipal water supply treatment plants are inadequately designed and overburdened. In most cities and towns, rain, household waste water, and industrial wastes enter the same collection system. Clean rain water becomes contaminated by polluted water. Overload from heavy precipitation floods sewage treatment facilities and allows polluted water to pass directly into rivers and streams.

In 1972, Congress took decisive action to renew water resources by amending the Federal Water Pollution Control Act, setting 1983 as the goal date for making the nation's rivers and lakes clean enough for recreational purposes and to help protect sources of drinking water from pollution. The Environmental Protection Agency (EPA) is managing billions of dollars, in partnership with state and local agencies, to attain this goal. Any measure the consumer can initiate to conserve water at home - even cold water - means saving energy indirectly.

The Residential Conservation Service

Across the country, States and utilities are preparing for a major effort to promote more energy efficient living. The provisions of Title II of the National Energy Conservation Policy Act (NECPA) require major utilities to offer their residential customers services that will enable them to save energy and money. The Residential Conservation Service (RCS) was formed to encourage the use of energy conservation and renewable resource measures in the homes served by large gas and electric utilities. Utilities are responsible for providing most RCS services. The following is a summary of RCS rules and regulations pertaining to water use and energy conservation; these are termed "Mandated Practices", which the RCS is required by law to include.

Water Flow Reduction: "Water Flow Reduction in Showers and Faucets: placing a device in a shower head or faucet to limit the maximum flow to three gallons per minute, or replacing existing shower heads or faucets with those having built-in provisions for limiting the maximum flow to three gallons per minuts." (RCS Rules and Regulations).

The cost of heating water depends on the amount of water used for household purposes. Low flow showerheads and faucets reduce the amount of water used for showering and washing. The low flow models operate by aerating the water and maintaining the pressure, while using less water. Flow restricting devices range from small discs which cost virtually nothing, to new faucets and showerheads which can cost up to $30.00.

Tank Temperature: "Reducing Hot Water Temperatures: Manually setting back the water heater thermostat setting to 120° F, and reducing the use of heated water for clothes washing." (RCS Rules and Regulations.)

Domestic hot water can account for up to 20% of residential energy costs. This consumption can often be reduced by half with no negative effects on health, comfort, or convenience. The "touch temperature" for hot water is 105° F. At 115° F, water can cause first degree burns. Many hot water heaters are routinely set at 150° F to 180° F. This high setting, like many other energy inefficient practices, was intended to guarantee almost endless hot water. On tank-type hot water heaters, the setting can be reduced to save a large amount of energy. On tankless units, the operating temperature can be reduced for summer operations. The thermostat on hot water heaters is prominently located and can easily be adjusted by the resident. The recommended setting is the one which provides adequate amounts of hot water with no need to blend in cold water for washing or bathing purposes.

WATER HEATING

Water heating is often the second-largest energy consuming system in the home, next to space heating or cooling. Domestic hot water is usually desired at a moment's notice, any time of the day, for bathing, dishwashing, laundry, or other uses.

Water heaters must, therefore, remain ready to supply large quantities of hot water, throughout every day of the year. To perform this task, the water heater must keep the water at a nearly constant, high temperature, determined by the thermostat setting.

Water Heating Costs

Little thought is given to the cost of heating water, because its use is constant rather than seasonal. But water heating accounts for about 20% of total residential consumption. There are several ways to conserve hot water and use it more efficiently, so that energy requirements and costs will be less.

The average person uses about 20 gallons of hot water each day. Water heater efficiency can be measured by looking at the number of gallons that can be heated 100° F in one hour, and comparing it to the Btu of energy required to obtain this temperature rise.

One gallon of water weighs 8.3 pounds. One Btu of energy is needed to heat one pound of water one degree Fahrenheit. Thus, 830 Btu is needed to heat a gallon of water 100° F.

Electric elements are rated in watts, and your electric bill is figured in $/Kwh. One Kwh equals 3414 Btu.

Water heater efficiency can be calculated by: $\frac{\text{Btu Output}}{\text{Btu Input}} = \text{Efficiency}$.

For electric water heaters, this is: Input equals 5500 watts (5.5 Kwh)
At 4-1/2¢/Kwh cost of operation: $0.045x5.5 = $0.25 per hour
Btu input = 18,777 Btu (5.5x3414)
Output = temperature rise of 100° F for 22.5 gallons
Btu output = (22.5)(8.3)(100) or 18,675 Btu.
Efficiency = (18,675)/(18,777), or 99.4%
Cost = 18,675 Btu for 25¢, or $13.39 per MM Btu.

Checking a number of electric water heaters indicates that these figures are typical. Electric water heater recovery costs about $13.25 per MM Btu at

$0.045 per Kwh. Tank efficiency is about 99.5%.

For natural-gas water heaters: Input equals 50,000 Btu/hour
At 2.70 per MM Btu = 13.5¢ per hour
Output = temperature rise of 100° F for 42 gallons
Btu output equals (42)(8.3)(100) or 34,860 Btu
Efficiency = (34,860)/(50,000) or 69.7%

Cost equals 34,860 Btu for 13.5¢, or $3.87 per MM Btu.

With these calculations, the cost of heating water with electricity appears to be about three-and-a-half times higher than that of heating water with natural gas.

What does this mean in 1977 annual costs? Assuming a family of four uses 80 gallons of 140° F hot water, which enters the house at 55° F:

(80)(8.3)(365) = 242,360 pounds of water per year
(242,360)(140-55) = 20.6 MM Btu per year.
Electric = (20.6)(13.25) = 272.95 per year or $22.75 per month
Gas = (20.6)(3.70) = 76.22 per year or $6.35 per month.

Natural gas prices are expected to rise by 50% shortly. So the future cost ratio might be about 1 to 2.4, gas to electricity. This gives the following estimate:

Gas equals $114.00 per year or $9.50 per month
Electricity equals $273.00 per year, or $22.75 per month.

Gas water heating would remain much more economical. However, electricity is available at lower rates during off-peak hours, such as during the night. This tends to make electricity somewhat more competitive.

Hot Water Equipment

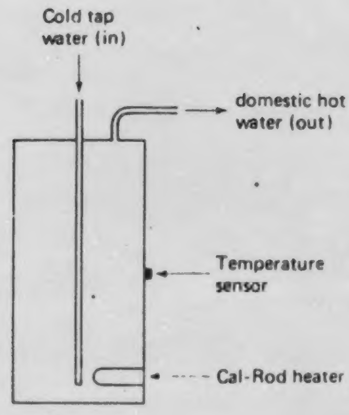
Hot water usage depends on the number of people in a household, the number of bathrooms, and on the presence and regular use of a clothes washer and/or automatic dishwasher. Water heating units, usually using gas, electricity, oil, or solar are specified in terms of tank size, rate of heat output, maximum estimated hot water usage per hour, and recovery or reheating capacity. An oversized unit may use energy to keep unneeded water hot; an undersized unit may not supply enough hot water. A reliable heating and plumbing contractor can determine the size tank needed by the resident.

If residents must replace a water heater, you should recommend that they make energy efficiency the main criterion. The resident should look for a system with a thickly insulated outer shell. Gas fired units should be chosen with an electric ignition system to eliminate pilot light energy wastes.

If possible, these units should be located close to areas of major hot water use. Twice a year (monthly in areas with heavy mineral deposit in the water), a bucket of water should be drawn from the hot water storage tank to help remove sediment, which insulates the tank from the source of heat.

Kinds of Water Heaters: Water heaters most frequently found in homes are either the free standing tank or the tankless coil type. Free standing tank water heaters (operating independently of the home heating system) heat water to a desired temperature and store it until it is needed. In tankless water heaters, when hot water is needed, cold water is circulated through a coil within the boiler of the heating system and is heated. Tankless systems are an integral part of the home heating system.

Conventional Systems: A conventional hot water heater for a residence is illustrated in Figure 4-3, shown on the following page. Tap water is introduced through a tube to the bottom of the tank. The entire tank is under the cold water line pressure (usually 40-80 psi). Hot water is drawn from the top of the tank, when a hot water tap is opened anywhere in the house. A sensor monitors the temperature on the wall at the middle of the tank, and when the temperature drops below a preset value (usually manually adjustable in the range 120° to 150° F), the gas jets or electrical resistance rods are turned on automatically by a thermostat. When the desired temperature is reached, the heaters are turned off by the thermostat.



Conventional hot water heater

Figure 4-3

The volumetric capacity of the heater is usually sized to be about 25-35% of daily usage. For a family of four that uses roughly 120 gallons per day of hot water, a 30 or 40 gallon tank is typically used. If the tap water temperature is, say 60^{o}F, and the hot water temperature is 130^{o} F, then:

$$(40 \text{ gal})(8.3 \text{ lb/gal})(1 \text{ Btu/lb-}^{o}\text{F})(70^{0} \text{ F}) = 23{,}240 \text{ Btu}$$

are required to bring a full tank of tap water up to hot temperature. For a gas-heated unit with, say, 80,000 Btu/hr input, if the burner efficiency is 60%, then 48,000 Btu/hr can be added to the water. Thus, the recovery time after large usage has depleted the tank of hot water would be (typically): (23,240 Btu)/(48,000 Btu/hr) = 1/2 hour.

Commercial hot water units can either be essentially scaled-up residential-type units, or can be "rapid recovery" units. A rapid recovery unit uses a very small volume compared to a day's usage (perhaps 5%) but has very high power input for rapid heating as hot water is used. This kind of unit reduces the space required for the hot water tank in an apartment complex, for example.

Domestic Water Heater: The domestic water heater is the source for supplying heated water in the home. Gas water heaters and electric water heaters operate much like a gas or electric furnace. If checked periodically and maintained properly, they will operate efficiently, giving the customer the most hot water for energy spent.

In addition to routine maintenance of water heaters, other measures can be taken to increase the efficiency of the water heater itself. In a typical household, heat loss through the tank walls accounts for approximately 25% of the energy consumed for heating the water. Additional losses occur through uninsulated service pipes. The burners and heating elements in the tank account for a great loss in efficiency, since a gas or oil burner is only 50-60% efficient in its configuration, and an electric heating element is only 33-40% efficient.

To help cut down on these heating losses, consider wrapping the water tank with a 2- to 3-inch batt of insulation. Place the insulation with the vapor barrier away from the tank. On an electric heater, cover the top as well as the sides, and secure with duct tape. On a gas or oil heater, the top cannot be covered because of water connections and the flue. There are also hot water blanket kits available from hardware and major catalog order stores for $20 to $25. This can cut heat loss and save about 400 Kwh/year for electric heaters, and about 3600 CCF/gas/year.

Hot water service pipes should be wrapped with 1/2-inch foam or fiberglass insulation. This is easy in new construction, but may be impractical in a standing structure. These two steps, however, can save 10-20% a year in hot water fuel bills.

Place the water heater near the major hot water users in the home and in a warm place. This will eliminate water traveling long distances and cooling in the pipes.

If the front of the water heater is removed for servicing or repair, be sure the insulation is repacked around the elements and the panel is replaced securely. This will eliminate air leakage.

Consider using a timer on an electric heater, especially if no one is home during the day. This will require the heater to be turned on only when needed, or during the peak periods of operation. Turn off the heater when going away for a weekend or vacation. It takes only three to five hours totally to heat a tank of water from cold tap water.

When selecting a water heater, be sure it is sized properly for the family needs. A typical family of four requires a 30-gallon gas or oil heater or a 50-gallon electric heater. It should have a thick insulation and a recovery rate of at least 75%, which means the tank will reheat 30 gallons in one hour.

Set the thermostat on 120° or 125° instead of 150°. This simple step can save as much as 25% of the fuel used annually to heat water, and will not cause any appreciable inconvenience to the users. This may be too low a setting for some families and therefore should be tried. Remember, the higher the setting, the more fuel will be used.

Another means of reducing the amount of energy used to heat water is to install a heat recovery system on the central air conditioner, heat pump, or fireplace. The unit is a heat exchanger with a circulation pump. The pump uses waste heat from the condenser fan on the air conditioner or heat pump, and transfers it to the water tank where it is stored. This acts as a preheat or auxiliary heat for conventional units and deserves consideration in those areas where air conditioners are used throughout most of the year, and where electric water heaters must be used.

Free Standing Tank Water Heaters: Free standing water heaters are generally energized by any of three energy sources: electricity, natural gas, and fuel oil. The methods for the transfer of heat vary for water heaters, depending on their energy source. Each system will be covered in detail later. First, we will discuss those features which are common to all systems, regardless of their fuel source.

The outer jackets of hot water tanks are usually made of sheet metal. Between the outer jacket and the actual water containment tank is usually a layer of one or two inches of glass fiber or other types of mineral wool insulation. The cold water pipe is normally connected to the top of the tank, and the cold water passes through a pipe or "dip tube" to the lower portion of the tank. Hot water is distributed from the upper portion of the tank and replaced with cold water from the dip tube near the bottom.

The water supply in some areas may contain corrosive elements, which could lead to deterioration of the containment tank in a process called galvanic corrosion. To reduce the corrosion of the tank through electrolysis, rods (usually magnesium) are installed in the tank. Because of the chemical properties of this metal, the rods will tend to corrode before the tank does.

A drain valve is usually located on the outside of the tank, near the bottom, to permit drawing off sediment which may accumulate on the bottom of the tank.

To prevent over-heating, free standing water heaters are usually equipped with a high-limit thermostatic switch, which will stop the heating if internal water temperatures reach a dangerous level. A pressure relief valve, usually located on the top of the tank, serves as an additional safety measure. If the temperature in the tank becomes too high, the pressure builds up and the pressure relief valve will open.

Electric water heaters operate by resistance elements within the water containment tank (Figure 4-4). These units can be equipped with either one or two elements. Models with two elements usually have one located in the upper portion, and one in the lower portion. Each element has an individual thermostat control found behind the access plates. As previously described, hot water is drawn from the top of the tank and replaced by cold water entering at the bottom through a tube.

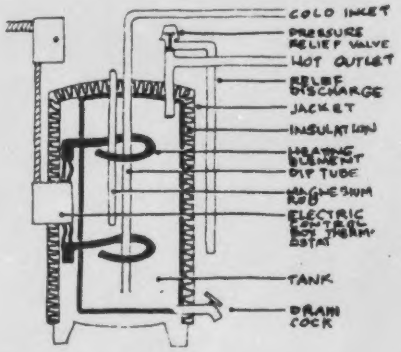


Figure 4-4: Electric Hot Water Tank

When the demand for hot water is low, the heating element in the lower portion of the tank operates to maintain the water temperature. As the demand for hot water increases, the heating element at the upper portion of the tank switches on to maintain the temperature of the hot water. The hot water is drawn from the top of the tank. Once the water at the top of the tank has reached the desired temperature, the top element turns off, and the lower element turns back on.

The heating surfaces for both gas and oil-fired water heaters (Figures 4-5 and 4-6) are near the bottom of the tank. Air enters the combustion chamber, combines with the fuel, and the mixture is ignited. Heat is then transferred to the water through metal surfaces at the bottom of the tank.

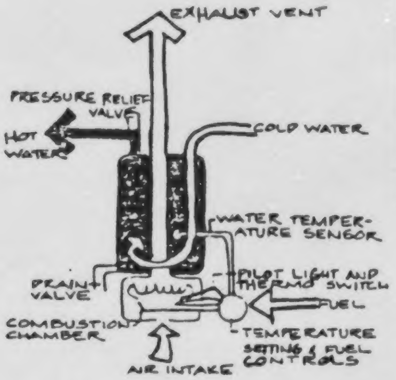

EXHAUST VENT
PRESSURE RELIEF VALVE
HOT WATER
COLD WATER
WATER TEMPERATURE SENSOR
PILOT LIGHT AND THERMO SWITCH
DRAIN VALVE
FUEL
COMBUSTION CHAMBER
TEMPERATURE SETTING & FUEL CONTROLS
AIR INTAKE

Figure 4-5: Hot Water Heater (Standing)

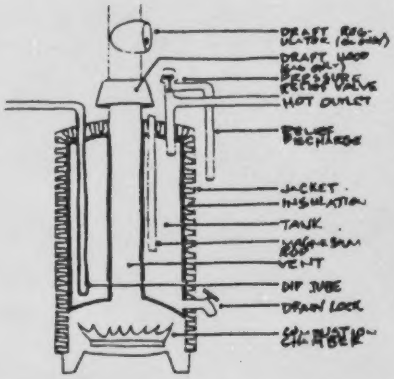

DRAFT REGULATOR (OIL ONLY)
DRAFT HOOD (GAS ONLY)
PRESSURE RELIEF VALVE
HOT OUTLET
RELIEF DISCHARGE
JACKET
INSULATION
TANK
MAGNESIUM ROD
VENT
DIP TUBE
DRAIN LOCK
COMBUSTION CHAMBER

Figure 4-6: Gas/Oil-Fired Water Heater

The vent pipe, an exhaust pipe which carries the by-products of combustion to the outside, also serves as a heat exchanger. This pipe is usually surrounded by the water containment tank, and often contains baffles to slow the escape of these gases through the vent, thus allowing more time for heat to be transferred to the water around the pipe.

Thermostatic controls regulating the temperature of the water are usually located near the mid-section of gas and oil-fired water heater tanks.

The proper mixture of additional air with combustion or exhaust gases is important in gas and oil-fired water heaters, to assist in the safe passage of combustion products to the outside. If their escape is impeded or blocked, serious problems can develop. To assure this proper mixture, gas-fired water heaters are equipped with a cone-shaped draft hood on the vent pipe, as it emerges from the tank.

Oil-fired water heaters are usually furnished with draft regulators attached to the vent pipe, between the tank and chimney. This is a hinged metal flap with a counterweight, to allow for variations in flue gas pressure.

Some gas or oil-fired water heaters may also be equipped with vent dampers on the vent pipe. This energy-saving device automatically closes the vent pipe to prevent the escape of heat to the flue when the main burner is not being fired. This, in turn, slows down the rate at which the water tank cools down.

Gas Water Heaters: The gas water heater is a tank of various gallon capacities, with insulated sides, and a flue through the center of the unit vented to the outside, as shown in Figure 4-7 on the following page.

Heat is provided by a circular burner located at the bottom of the tank. The gas valve and thermostat are usually combined in one assembly, and located on the outside front of the tank. This allows gas to be fed to the burner and shut off when the water has reached a certain temperature. A thermocouple acts as a safety device which shuts off the gas valve, if the pilot light should go out. The tank is often glass-lined and retains heat similar to a thermos bottle. The amount of insulation varies from 1-1/2 inches to about 3 inches. Becoming acquainted with these features and paying close attention to their proper operation helps dispel the mystery and helplessness some people have if something goes wrong with the hot water heater.

The consumer should periodically check the tank for cracks, leaks, and proper gas, water, and flue/pipe connections. Any means by which heat or hot water can escape constitutes a waste of energy. Check the burners for cracks or breaks, and clean them for proper burning. Make sure the flue is free from obstructions and has a rain cap. Birds often build nests in warm flues which are not capped. Once a month, flush the tank to rid chemical impurity build-up and rust. Clean dust and grease buildup from the thermostat and valve housing and connecting wires.

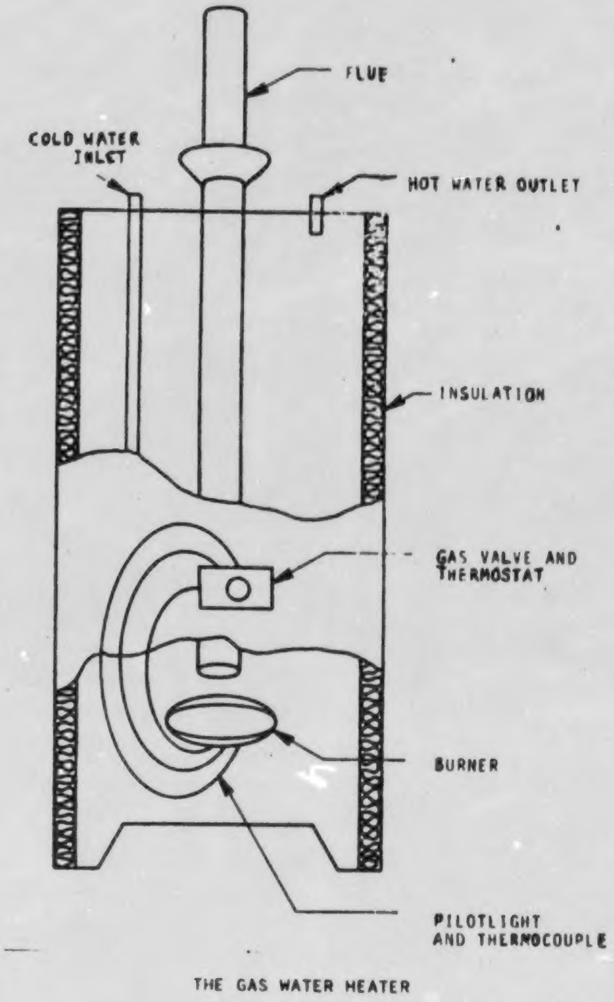

FLUE
COLD WATER INLET
HOT WATER OUTLET
INSULATION
GAS VALVE AND THERMOSTAT
BURNER
PILOTLIGHT AND THERMOCOUPLE
THE GAS WATER HEATER

Figure 4-7

Electric Water Heaters: The construction of electric water heaters, unlike gas heaters, varies, depending on the type and placement of the heating elements. The heating elements of electric heaters may be wrapped around the tank or submerged within, may have one heating element or two elements, and may require 120 or 240 volts for operation. The volume size of an electric water heater must be larger than a gas heater for comparable service. For instance, the average gas hot water tank size for a family of four is 30 gallons. The required size of an electric water heater for the same family is 50 gallons. The reason for this is that an electric water heater cannot heat water as quickly as gas, and therefore requires a larger initial heated volume.

There are advantages to an electric water heater, however. It can be completely surrounded by insulation instead of insulating only the sides, as with a gas heater. An electric unit requires no flue pipe, allowing placement anywhere in the home. Operating costs, however, are much greater for an electric water heater than for its gas counterpart.

Most electric water heaters use 240 volts, with only the smaller ones using 120 volts. Dual heating element models provide more hot water than single-element ones, but cost more in initial price and operating costs. In a dual element model, the main heating element is located near the bottom, where cold water enters the unit. As hot water is drawn from the tank, cold water enters the bottom of the tank and activates the bottom heating element, as shown in Figure 4-8, which appears in the following pages.

For normal use, this is the only heating element needed to heat the water. If there is a great demand, the upper element will heat. The heating elements in Figure 4-8 are belted types, which wrap around the outside of the tank. The insulation and outside casing cover the heating belts. Figure 4-9, which appears in the following pages, shows an electric water heater which uses two submersible heating elements. The principle is the same as with the belted heating elements in Figure 4-8.

Each of the two elements has its own thermostat to control the temperature of the water. The top element heats first and remains on until the required temperature is reached by the top thermostat. The top thermostat then turns off its heating element and turns on the bottom element. Each of the two elements may be the same wattage rating or may differ, such as 4500 watts for the bottom element and 2500 watts for the top element. Quick-recovery water heaters have higher wattage ratings than regular models, use more energy, and require heavier gauge wire to operate.

Routine maintenance is important on an electric hot water heater, because cracks in the outer case can allow water to come in contact with the heating element. This provides a path for electricity to ground, which causes an unnecessary drain on the electricity.

THE BELTED-ELEMENT ELECTRIC WATER HEATER

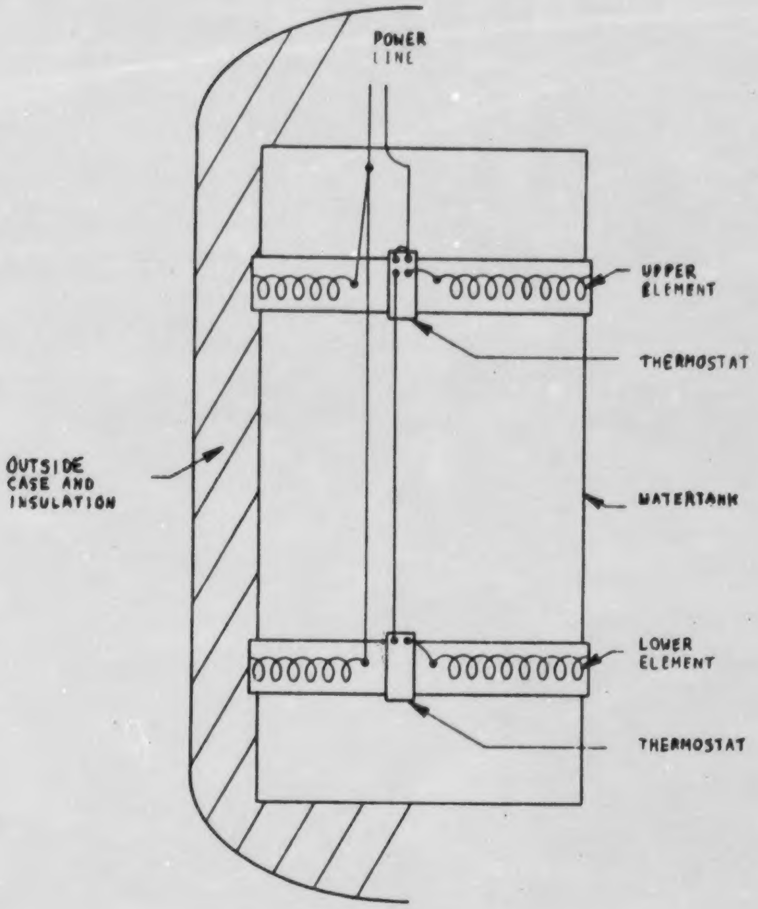

POWER LINE
UPPER ELEMENT
THERMOSTAT
OUTSIDE CASE AND INSULATION
WATERTANK
LOWER ELEMENT
THERMOSTAT

Figure 4-8

THE SUBMERSIBLE-ELEMENT WATER HEATER

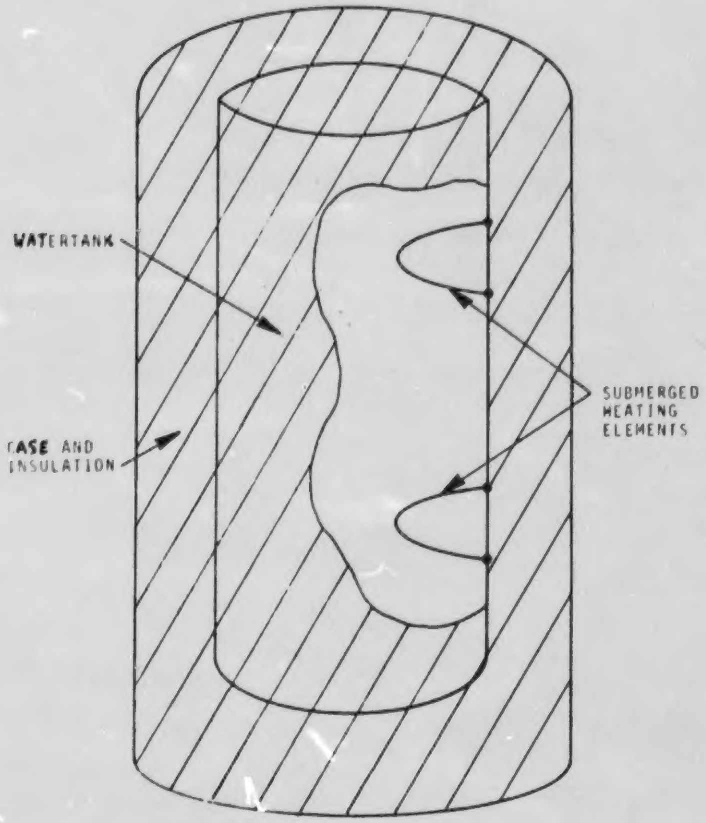

WATERTANK
CASE AND INSULATION
SUBMERGED HEATING ELEMENTS

Figure 4-9

Tankless Water Heating Systems: Tankless water heaters are designed for use in colder climates. They use boiler heat operating in conjunction with the home heating system (Figure 4-10), and the water circulating within the boiler to heat the home also heats the domestic water. This is accomplished by a coil-type heat exchanger immersed in the boiler water within the furnace. When hot water is demanded, the cold water passes through this coil and is heated. This heated water is then piped from the boiler directly to its destination.

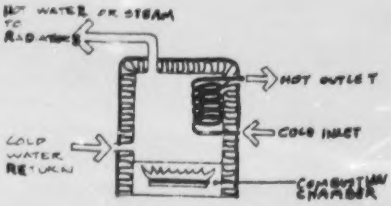


Figure 4-10: Tankless Hot Water

In cold climates such systems are very efficient during the heating season, since boilers operate frequently at that time. There is usually an adequate supply of boiler heat to supply moderate amounts of domestic hot water. When the demand for hot water is high, the boiler will cool down because of the large influx of cold water it must heat.

In warm weather, these systems are less efficient, for the furnace must switch on simply to heat the hot water, even if there is no need to heat the home. This can add heat to the home, even though the distribution system is not in operation.

Efficiency of Water Heaters: In a gas-fired water heater, combustion efficiency is important. A periodic maintenance check by a competent serviceman is recommended. Also, most gas water heaters contain a continuously burning pilot light. There is some waste - about 30% of the pilot gas burned. An alternate ignition device for an automatic pilot flame is available.

In both gas and electric water heaters, the major losses are through the tank insulation jacket. The surface areas of three common sizes of water heaters are shown in Figure 4-11, which will appear on the following page. Assuming the tank is at 140° F in a building at 70° F, the temperature difference between the tank and its surroundings is 70° F. Heat is constantly being radiated away from the tank.

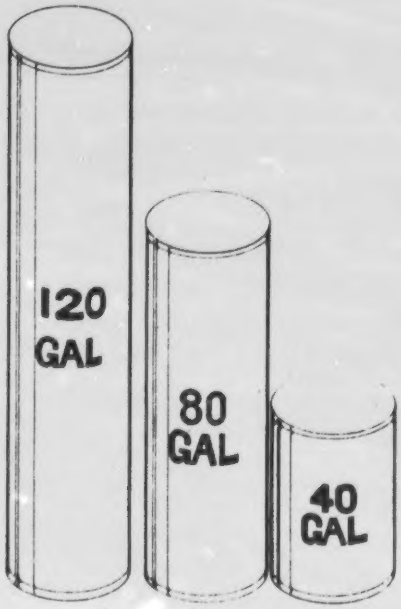


Figure 4-11: The Surface Areas of Three Common-Size Water Heaters

Figure 4-12 shows the effect of three insulations on the tanks. Using these heat loss figures, you can calculate how better insulation might reduce the water heating costs. For instance, an 80-gallon tank with U = 0.2 insulation loses about 3.6 MM Btu per year:

(413 Btu/hr)(24 hr/day)(365 days).

INSULATION VALUE	Btu LOSS/HR		
	40 GAL	80 GAL	120 GAL
U = .2 (R-5)	273	413	542
U = .1 (R-10)	137	207	271
U = .05 (R-20)	68	104	136
No Insulation	1365	2065	2709

Figure 4-12: Insulation Has an Effect on the Heat Loss From Water Heaters.

The same tank with U = 0.05 insulation would lose only about 0.91 MM Btu per year:

(104 Btu/hr)(24 hr/day)(365 days).

At a cost of $9.30 per MM Btu (an average figure between gas and electricity), the losses from the first tank would be $33.48 a year, or $2.79 per month. The losses from the second tank would be only $8.46 a year, or $0.71 per month. Upgrading the insulation would save $25.02 a year or $2.08 a month.

By comparison, an uninsulated 80-gallon tank would lose 18.1 MM Btu per year. The cost would be $168.33 or $14.02 a month.

Water Heater Insulation: The Residential Conservation Service Rules and Regulations provide the following definition: "The term 'water heater insulation' means a material primarily designed to resist heat flow, which is suitable for wrapping around the exterior surface of the water heater casing."

Insulating Free Standing Water Heaters: Free-standing water heaters must maintain water temperatures higher than the temperature of their surroundings. They are thus clearly subject to conductive heat loss. Heat escapes through the walls of the tank, from the warm inside area to the cooler outside area.

Conductive heat loss in water heaters is affected by the surface area of the tank, the period of time for which the water must be heated, the temperature difference between the water and its surroundings, and the insulating qualities of the materials between the water and its surroundings. The first three factors, surface area, time, and temperature difference, involve energy saving practices common to any conductive heat transfer process.

When safety permits, water heater insulation is an energy-conserving measure. It requires an investment of money for materials, and possibly for labor. Insulation for free-standing water heaters is usually most effective if the unit is located in an unconditioned area. If the water heater is located in a conditioned area, the difference between the desired water temperature and the average ambient air temperature becomes crucial. Payback periods for money invested in insulating materials will be shorter for tanks located in unconditioned, cool areas than for those located in conditioned, warm areas.

Newer-model free-standing water heaters usually contain up to two inches of mineral fiber insulation between the outer jacket and the tank. They may be sufficiently insulated, and may not require additional insulation.

In situations which do call for retrofit, the insulation is wrapped around the exposed exterior surfaces of free-standing water heaters.

If the insulation is not properly installed, serious problems could result. Insulation for all water heaters should be applied with the facing (vapor barrier) to the outside. Insulation should not cover the operating instructions of the unit.

Insulating Gas-Fired Water Heaters: Gas-fired water heaters equipped with a pilot light and a vent damper should not be insulated. Doing so could lead to overheating, because heat from the continuous pilot light does not readily pass through a closed vent.

If the unit does not have a vent damper, retrofit insulation must be cut to leave openings for the burner air inlet at the bottom, the thermostat control, the pilot light access plate, the drain valve, and other necessary access plates (see Figure 4-13).

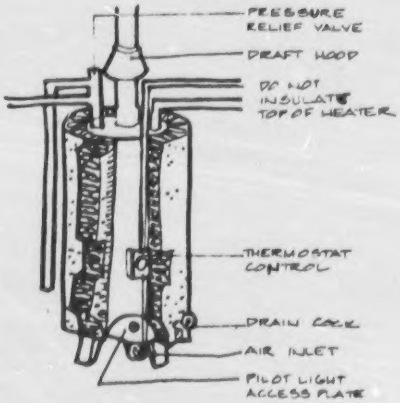


Figure 4-13: Gas-Fired Water Heater Insulation

Because of the danger of overheating due to the pilot light, the top plate should also remain uninsulated. The draft hood must not be blocked by insulation. If this happens, it might prevent carbon monoxide from properly venting to the outdoors, thereby causing a hazardous situation to building occupants.

Insulating Oil-Fired Water Heaters: Insulation on oil-fired water heaters should not cover the pressure relief valve, the thermostat control, the flame observation door, the burner access plate, the drain valve, or other necessary access plates. If the vent pipe is top-mounted, insulation should not be installed on the top plate (see Figure 4-14).

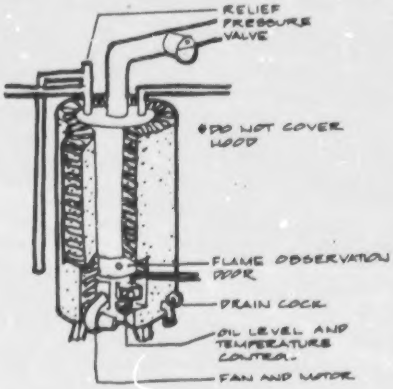


Figure 4-14: Oil-Fired Water Heater Insulation

If the vent pipe is side-mounted, maintain the minimum vent connector clearances specified in the latest edition of NEPA 211, Standards For Chimneys, Fireplaces, and Vents. (This could be as much as 18-inches for single-wall metal pipe chimney connections.)

Insulating Electric Water Heaters: For electric resistance water heaters, the top plate and the sides can be covered with insulation. The pressure relief valve, the thermostat controls, and the drain valve, must all remain unobstructed by insulating material (see Figure 4-15, which is shown on the following page.)

Insulating Tankless Water Heaters: With tankless water heating systems, the entire furnace operates during warm weather, as well as during cold weather. Any measure which improves the efficiency of the heating plant will also

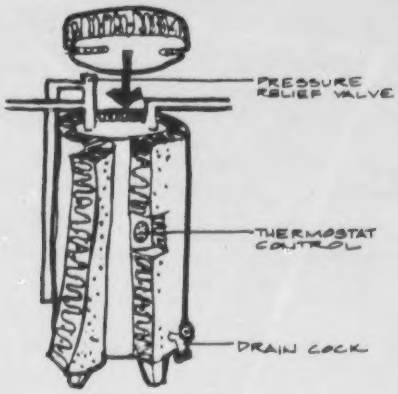


Figure 4-15: Electric Water Heater Insulation

improve the efficiency of tankless water-heating systems. This includes: regular furnace maintenance; burner/boiler replacements; or vent dampers.

Because tankless water heating systems are usually built into the home heating plant, it is not possible to insulate the coil. If, however, the coil is not located within the heat exchanger, it might be possible to insulate it. Take care not to interfere with combustion air access or the vent pipe, if insulation is applied. Consult with an oil service technician before recommending this measure.

Insulating Water Pipes: The following is a summary of pre-installation procedures from the Residential Conservation Service standards applicable to insulating water pipes.

Pre-Installation Procedures: Before any insulating improvement can be considered, a potential installer and the resident should do a pre-installation inspection, to be certain which areas of the home (i.e., water pipes) are conditioned, and thus subject to insulation improvements which would reduce heat loss (and energy use).

Identification: Pronounced streaks or actual spraying or dripping from a water pipe or from a space containing a pipe.

Evaluation: Check for water while pipe is under normal operating pressure for at least 15 minutes.

Correction: Repair piping in accordance with good plumbing practice. Where local code requires, repairs are to be made only by approved personnel.

The Residential Conservation Service Rules and Regulations provide the following definition: "The term 'pipe insulation' means a material primarily designed to resist heat flow which is installed on a heating or cooling pipe in an unconditioned area of a building."

The delivery pipes of both free-standing and tankless water heating systems can also be insulated.

In unheated spaces, domestic hot water and boiler steam and hot water pipes should be insulated, to prevent excessive heat loss. Before insulating, repair leaky pipes. Several insulations are designed specifically for hot water pipes (see Figures 4-16 and 4-17).

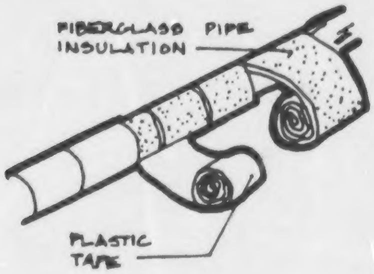

FIBERGLASS PIPE INSULATION
PLASTIC TAPE

Figure 4-16: Hot Water Pipe Insulation-Fiberglass

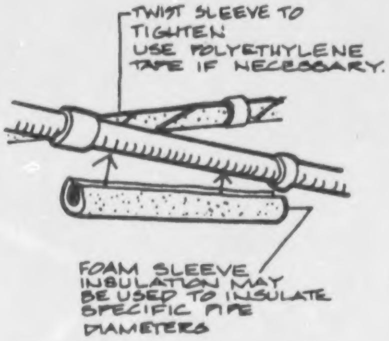

TWIST SLEEVE TO TIGHTEN. USE POLYETHYLENE TAPE IF NECESSARY.
FOAM SLEEVE INSULATION MAY BE USED TO INSULATE SPECIFIC PIPE DIAMETERS

Figure 4-17: Hot Water Pipe Insulation - Foam Sleeves

Steam pipes can also be insulated. Be sure the insulation can withstand the steam pipe temperature.

Do not insulate pumps, valves, boiler feed lines, pressure relief devices, or vents. In many cases insulation will prevent necessary heat escape.

Conserving Hot Water

The following tips are contained in the Residential Conservation Service Rules and Regulations as optional practices in use of a home.

"Off Peak" Water Heating - by taking showers, doing laundry and running the dishwasher at night, residents can reduce their peak hot water demands, if they live in a region with peak pricing for electricity.

Only full loads of laundry should be washed and the water level or load size devices on the washer should be used.

Use the lowest possible water temperature for the wash cycle of the clothes washer, and use cold water for all rinse cycles. Presoaking heavily soiled clothes before washing is a help.

Dishwashers should be run only once a day and only when fully loaded.

For washing dishes by hand, a pan with hot water should be used for rinsing.

Quick showers rather than baths use up to 50% less hot water.

Hot water should not be run continuously during shaving. The drain should be closed and the basin filled with water instead.

Energy-Saving Tips for Hot Water Use: The following are some general tips for energy savings in hot water use.

1. Develop an energy-conscious attitude toward using hot water - the most effective means of conserving energy used for water heating is toward hot water use. This may require breaking some habits, but it will not place an unnecessary strain on hot water use.
2. Repair leaky faucets! A 1/32-inch steady stream of water leaking from a hot water faucet could add up to 6000 gallons wasted in one year, or the equivalent of 200 baths. Water leakage accounts for between 5-10% of all residential water consumption. To correct this problem, replace any worn washers. Consider replacing a conventional faucet with a single handle washerless valve faucet.

This type faucet uses two smooth ceramic or hard plastic disks instead of a washer and seat, and produces a complete water seal. The washerless valve usually comes with a lifetime guarantee from the manufacturer, which makes it maintenance-free and attractive.

3. Replace conventional washers with flow-reduction devices in kitchen sinks, shower heads, bathroom lavatories, and utility sinks. These are usually a metal fitting threaded at both ends for easy installation, a plastic "spool" inserted directly into the pipe, or any device that reduces the diameter of the water line. Without these devices, normal flow rates can be up to 12 gallons of water per minute. With them, the flow rate can be reduced to as little as 2 gallons of water per minute. A low-flow faucet may require more patience when filling a pail, but at 2 gallons per minute, it will only take 15 seconds to fill 2 quarts, which is not too inconvenient. Do not use flow reducers on faucets which supply dishwashers and clothes washers. These appliances operate on proper amounts of water filling the appliances in a timely manner. Restricting the flow will put an undue strain on the appliance, causing breakdown and added expense.

SOLAR WATER HEATING

Heating of water for bathing, washing, or commercial purposes is one of the oldest and most cost-effective uses of solar energy. The temperature levels required (100-140° F) can be produced efficiently by simple, relatively inexpensive collection devices. In addition, the demand for hot water tends to be uniform throughout the year, unlike space-heating demands which peak during the winter months when solar energy is least available. The combination of moderate temperature requirements and uniform annual demand makes the production of hot water for domestic, commercial, and industrial uses a particularly attractive application for solar energy.

Solar heating of domestic water has occurred on a significant scale in the United States, Israel, Japan, and Australia. Solar domestic hot-water (DHW) systems appeared in Florida during the 1920's. The comparative costs of a simple thermosiphon solar system versus available alternate fuels in Florida created a viable solar hot-water heating industry. Thermosiphon systems were installed at an increasing rate until 1941, when it was estimated that approximately 60,000 installations had been made in the Miami area. Sales of solar water heaters steadily decreased after 1941, until only a few new installations per year were made during the 1960's. The decay of the industry is attributed to three factors. First, the solar system lost its economic advantage as electric energy costs decreased and the cost of solar equipment increased. Second, negative homeowner attitudes arose as steel storage tanks developed leaks. Third, large-scale builder-developers were reluctant to add the cost of a solar system to a house in a price-competitive market. The convergence of these three factors during the 1950's made the solar hot-water industry essentially dormant in Florida, until renewed activity was spurred in the mid-1970's by rising energy costs and concerns about the long-term availability of fossil fuels.

Solar Heating Systems

The Solar Heater: All solar heating systems operate in much the same way. The basic parts of the system are: the collector, storage, distribution, controls and auxiliary energy source. The flat-plate collector is the most widely used type for low-temperature water heating. Most collectors use liquid as the heat-transfer medium; however, some systems use air for water heating.

Figure 4-18, which appears on the following page, shows a collector with the following components: glazing (A), usually double-strength glass installed with gaskets or caulking to allow expansion and contraction due to temperature changes; water tubes (B) that are attached above, below, or integral to the absorber plate for heat transfer; the absorber plate (C) which usually is metal and is treated with a black paint or dark "selective" coating to improve the plate's ability to absorb heat. The selective finishes are special coatings which absorb most of the sun's rays, thus increasing the efficiency of the collector. The insulation (D) must be able to withstand high temperatures that occur when the collector is operating. The enclosure (E) is a container for the components listed above. Together with the glazing, the enclosure makes the collector weathertight.

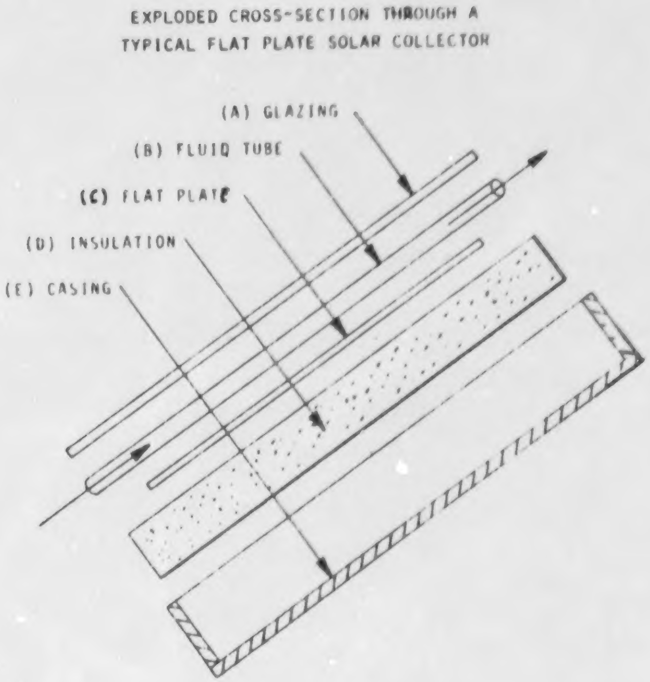

EXPLODED CROSS-SECTION THROUGH A TYPICAL FLAT PLATE SOLAR COLLECTOR
(A) GLAZING
(B) FLUID TUBE
(C) FLAT PLATE
(D) INSULATION
(E) CASING

Figure 4-18.

Circulation System: The circulation system, or loop, consists of piping that connects the solar collectors with a storage tank and moves the fluid with pumps (or by natural convection methods). The liquid in flat-plate collectors is circulated through a system of insulated and weatherproofed pipes to the storage tank and back to the collector.

Several terms should be understood relative to system circulation. There are "closed-loop" and "open-loop" systems. In a "closed-loop" system, the piping is sealed off from the atmosphere (air) and from the water in the storage tank. An "open-loop" system is open to the atmosphere during operation. Open-loop systems are nonpressurized; closed-loop systems are pressurized.

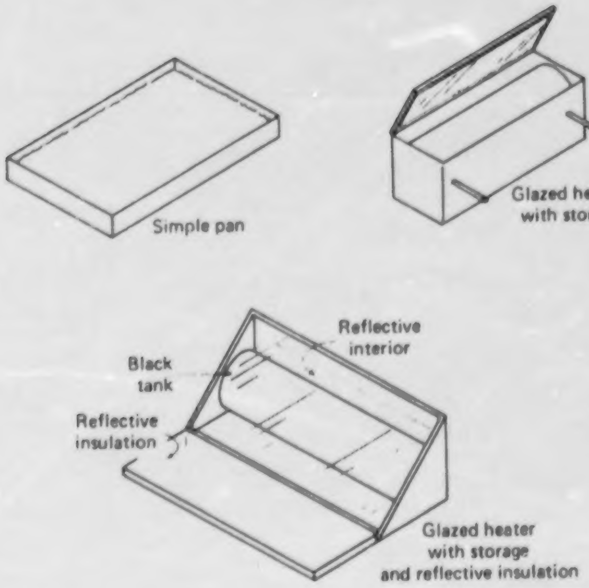
There are "direct" and "indirect" system designs. "Indirect" systems generally use a heat exchanger to transfer the collected heat to the storage medium. Indirect systems are commonly used to protect the potable water supply from a toxic circulatory antifreeze mixture used for system freeze protection. In a "direct" system, potable water is circulated through the collector loop without using a heat exchanger in the storage tank.

A heat exchanger is any device which transfers heat from one substance to another without mixing the two. In active systems, heat exchangers transfer heat across an enlarged surface area, while maintaining separation of the heat transfer fluid in the collector loop from the domestic water supply in the storage tank. This keeps the domestic water supply from being contaminated. Also, with a heat exchanger, only a small portion of the total amount of system fluid must be treated to prevent system corrosion or freezing. Although heat exchangers are usually built around the hot water storage tank, they also exist as separate units.

Solar-heated water is stored in a well-insulated storage tank, which ranges in size from 65-100 gallons, for a hot water system.

There are three basic kinds of systems being used today for most solar water heating - the simple, direct system; the direct forced-circulation system; and the indirect forced-circulation system. All direct systems require a drain-down feature that allows all water to drain out of the collectors in order to prevent freeze damage.

Passive Water Heaters: A variety of techniques, ranging from very simple to complex, have been employed to produce hot water using solar energy. A blackened container filled with water and placed in sunlight represents possibly the simplest approach to a solar hot-water system. As we know, water exposed to sunlight will become warm. Three passive water heaters are illustrated in Figure 4-19, which appears on the following page. There are several variations of this simple there, mostly involving the inclusion of a glazing layer to reduce heat loss, tilting the collector toward the sun, and including pipe connections for easy filling and discharging. These types of collectors provide for solar heat collection and storage in one unit. While they work well on sunny days, they can lose tremendous amounts of heat during the night and on cloudy days. Nighttime insulation with a reflective inner surface can significantly reduce these losses while increasing gains during sunny periods, by reflecting additional solar energy onto the collector/storage unit.


Simple pan
Glazed heater with storage
Reflective interior
Black tank
Reflective insulation
Glazed heater with storage and reflective insulation

Passive water heaters

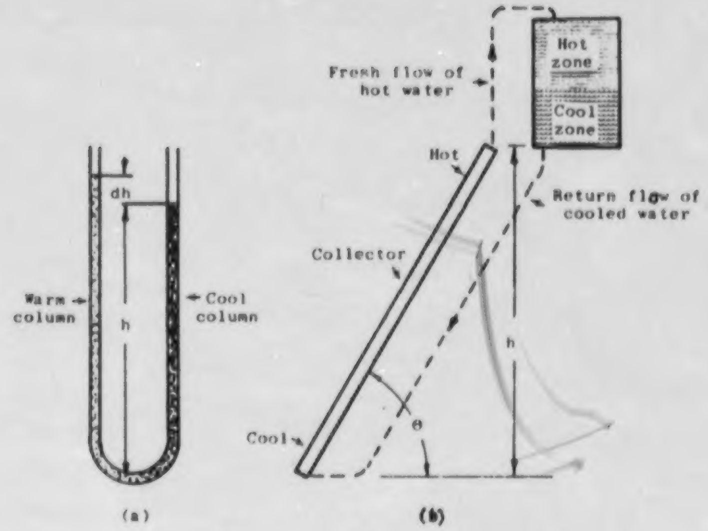
Figure 4-19.

Convective Self-Flow Thermosiphon: The density differential created by temperature gradients is used to cause the fluid being heated to flow without any external power source other than sunlight. The effect of convective self-flow is generally termed the thermosiphon effect. The magnitude of the effect and the velocity of fluid flow can be calculated on the basis of simple physical principles.

In Figure 4-20, which is on the following page, there is shown (a) a U-shaped tube containing fluid of a total depth h. If the tube is inclined with respect to the vertical, the value of h is the elevation difference, or (L)(cos θ), where L is the length of the tube and θ is the angle of tilt measured from the zenith. If one side of the tube is heated with respect to the other, the density, D, of the fluid in the heated column will be lowered, but because the two columns are self-balancing, the length of the column in the hot side will be increased a distance dh for the weights in the two columns to be equal. We thus have:

$$D_{warm} < D_{cool}$$

$$h_{warm} = h_{cool} + dh$$


dh
Warm column
h
Cool column
(a)
Fresh flow of hot water
Hot zone
Cool zone
Hot
Return flow of cooled water
Collector
h
θ
Cool
(b)

Schematic diagram of the thermosiphon system for hot water. For proper operation the storage tank must be placed above the top of the solar collector.

Figure 4-20.

The incremental column dh represents a pressure head, and if the tube is cut off on the hot side at height h this force increment will accelerate the entire loop of material. The force causing the velocity of flow to arise is:

$$F = DdhAg = ma$$

where:
A is the cross-sectional area of the tube,
g is its gravitational acceleration, and
a is the acceleration induced by the force, F
m is the total mass.

Substituting $m = 2AhD$ for the total mass of the fluid to be placed in motion, we solve the equation for the acceleration and find:

$$a = gdh/2h$$

whence the velocity of flow by the equation $v^2 = 2as$, where $s = dh$, is:

$$v^2_{flow} = gdh^2/h$$

But because $dh = kh\Delta T$, where k is the coefficient of heat conductivity and ΔT is the temperature difference, we have for the final equation for the velocity of flow:

$$v_{flow} \leqslant (gh)\ 1/2\ k\Delta T.$$

The inequality in this last equation means that this velocity is that which would occur if there were no impeding forces in the fluid flow. For low velocities the frictional forces impeding the flow will be small. In an actual solar collector, however, the temperature of the water ranges from cool water entering at the bottom to hot water exiting at the top. Because the column is not therefore isothermally hot, the head dh is approximately one-half that for the isothermal case, and we have:

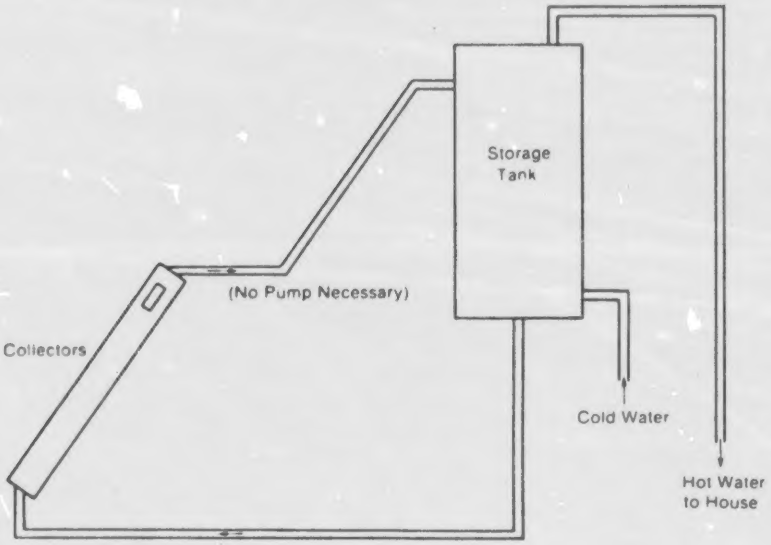
$$v_{flow} \leqslant (gh/2)\ 1/2\ k\Delta T.$$

The velocity of flow will be reasonably approximated by this equation until the opposing pressure head reaches a value of approximately 0.1 of the thermal pressure head.

The practical application of the thermosiphon to hot-water heaters is shown schematically in Figure 4-20b. The location of the storage tank above the collector is a requirement, even though this location is not aesthetically attractive. Also, the cold water makeup for the hot water used from the tank must be at the bottom of the tank to provide the proper head of dense, cool water.

Thermosiphon Systems: Thermosiphon hot water systems are generally considered to be passive solar energy systems, because they do not use pumps or valves. They are described here because of their association of the subject of water heating. In addition, comparison of the different solar water heating systems is more straightforward.

Figure 4-21, which appears on the following page, shows the components of a thermosiphon hot water system. This type of system is used in warm climates. Potable water circulates through the collector loop. Thermosiphon systems rely on the principle that water warmed in the collector is less dense than the cooler water entering the collector; the warmed water rises to the top of the storage tank, generally located above the collector. The bottom of the



Simple Schematic of a Thermosyphon System

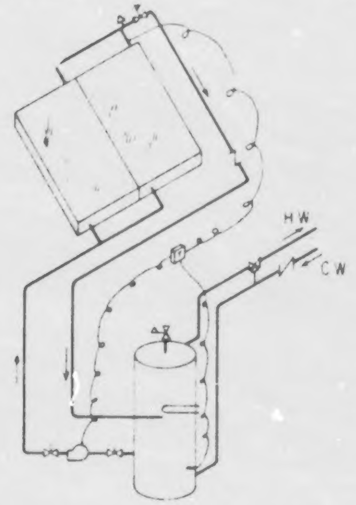
Figure 4-21.

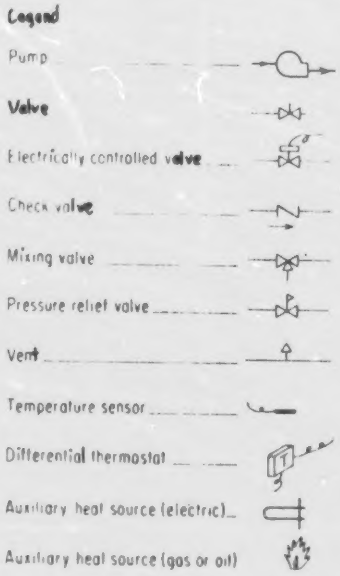
storage tank is 1 to 1-1/2 feet higher than the bottom of the collectors, and the top of the tank is similarly higher than the top of the collectors. This placement of system components permits the "convective (thermosiphon) loop" to operate effectively. Locating the storage tank can be more of a problem with thermosiphon systems than with other types of solar systems. Rarely-needed freeze protection is provided by "reverse thermosiphon", or heat tape on the collectors, among other methods (such as draindown).

Thermosiphon systems require no antifreeze and produce highly efficient heat transfer. They are relatively simple, inexpensive systems to install. No pumps or controls are required.

Direct Systems: A forced-circulation, or pumped, system may be either "direct" or "indirect". A direct system is one in which the potable or service water is heated by circulation through the solar collectors. Direct systems are generally used in climates which do not impose freezing problems, although methods such as draining collectors at night, trickle circulation, flexible collector waterways, etc., may be used to prevent expansion damage due to freezing in a direct system. The simplest type of direct forced-circulation

DHW system is the single-tank configuration shown in Figure 4-22. In this system, tap water is circulated through the collectors and stored in a single tank, which contains the auxiliary heating source (normally an electric element). Efficient operation of this system depends on maintaining thermal stratification in the tank. For this reason, the auxiliary heating element should be placed near the top of the tank, which precludes the use of oil or gas as the auxiliary energy source. A direct system with a preheat tank and separate auxiliary tank is shown in Figure 4-23. Thermal efficiency of this system does not depend on stratification in the auxiliary tank; so gas, oil, or electricity may be used as the auxiliary energy source.




Legend
Pump
Valve
Electrically controlled valve
Check valve
Mixing valve
Pressure relief valve
Vent
Temperature sensor
Differential thermostat
T
Auxiliary heat source (electric)
Auxiliary heat source (gas or oil)

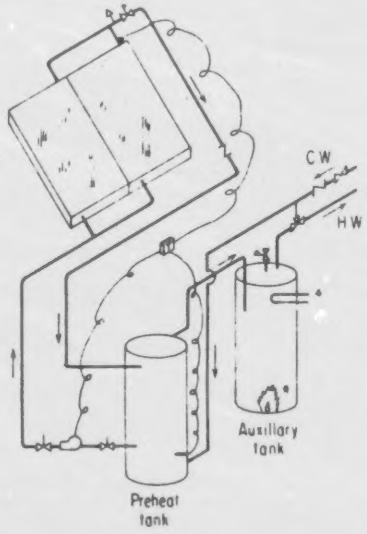

CW
HW
Auxiliary tank
Preheat tank

Figure 4-22: Direct Solar Water Heating with a Single Tank.

Figure 4-23: Direct Solar Water Heating with Preheat Tank and Separate Auxiliary Tank.

Since tap water circulates through the collectors in a direct system, methods of preventing damage due to freezing are limited. In mild climates, the pump may be turned on to cause circulation of warm water in the collectors, when the ambient outside temperature drops below freezing. In a severe climate, the procedure would result in excessive energy loss and a significant risk of a freezing condition coincident with a power failure. Automatic draining of direct-system collectors and outside piping whenever the pump is not operating can be accomplished.

In addition to the freeze prevention problem, the presence of tap water in the collectors in a direct system imposes a constraint on the choice of materials which may be used for the collector waterways.

Draindown Systems: In active solar systems employing a liquid heat transfer medium, the liquid must be protected from freezing and boiling. When potable water is used as the heat transfer medium, system freeze protection is generally provided by a draindown system. In this system, potable water is circulated from the storage tank through the collector loop and freeze protection is provided by solenoid valves opening and draining all the water in the collectors at a preset low temperature. A simple schematic of a draindown system is shown in Figure 4-24. Collectors and piping must be pitched (or tilted), so that the system will naturally drain down, even in a power failure. This type of system is exposed to city water line pressure and must be assembled carefully to withstand pressures as high as 100 pounds per square inch. Pressure-reducing valves are used when city water pressure is greater than the working pressure of the system. System protection is dependent on the successful operation of solenoid valves during freezing conditions. There are generally three solenoid valves in the system. An auxiliary heating element (electric) always keeps water at the top of the tank hot. Well-insulated tanks reduce heat losses.

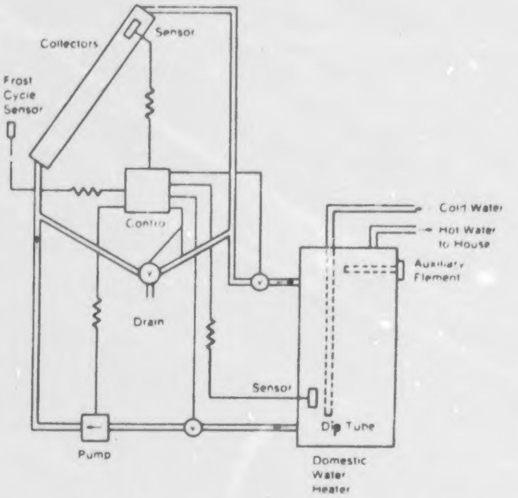


Figure 4-24. *Simple Schematic of a Draindown System*

A draindown system uses potable water only, with no antifreeze. Only small pumps are needed, owing to city water supply pressure. Since no heat exchangers are required, heat transfer to storage is more efficient. The system drains down only for freeze protection, and then loses less than one gallon of water per solar panel.

The three fail-safe solenoids use control wiring more complex than that used with other systems. Pipe corrosion can also occur. Draindown systems are not best in climates where it freezes most winter nights.

Draindown System With Preheat Tank: Automatic draining of direct-system collectors and outside piping whenever the pump is not operating can be accomplished using solenoid valves, as shown in Figure 4-25, demonstrating a direct solar water heating loop with preheat tank. This arrangement can be made fail-safe with respect to a power outage, but an undetected failure to close either of the drain valves could cause a significant waste of water.

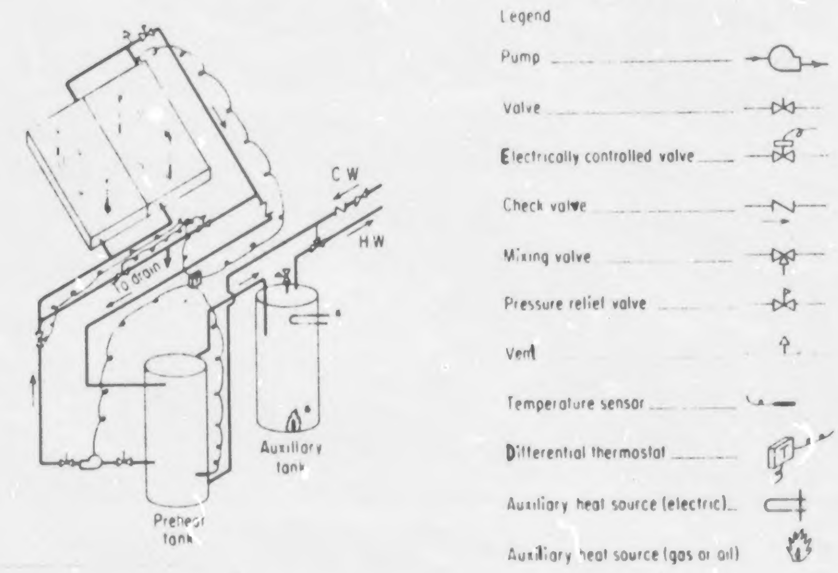

C W
H W
To drain
*
Auxiliary tank
Preheat tank
Legend
Pump
Valve
Electrically controlled valve
Check valve
Mixing valve
Pressure relief valve
Vent
Temperature sensor
Differential thermostat
Auxiliary heat source (electric)
Auxiliary heat source (gas or oil)

Figure 4-25: Direct Solar Water Heating with Preheat Tank and Automatic Draindown; * means either auxiliary energy source is acceptable.

Heat-Pipe Systems: The accompanying Figure, 4-26, shows a solar water-heating system proposed by F. deWinter. The auxiliary tank is heated by a heat pipe activated by any auxiliary fuel. Because of the heat-diode characteristic of heat pipes, no heat is lost during periods of no-auxiliary use. In addition, the pipe connecting the solar preheat tank and the auxiliary tank acts as a heat diode very effectively separating these two tanks thermally, although they are part of the same assembly.

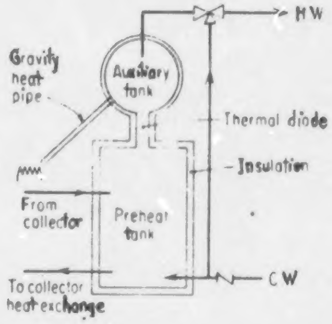
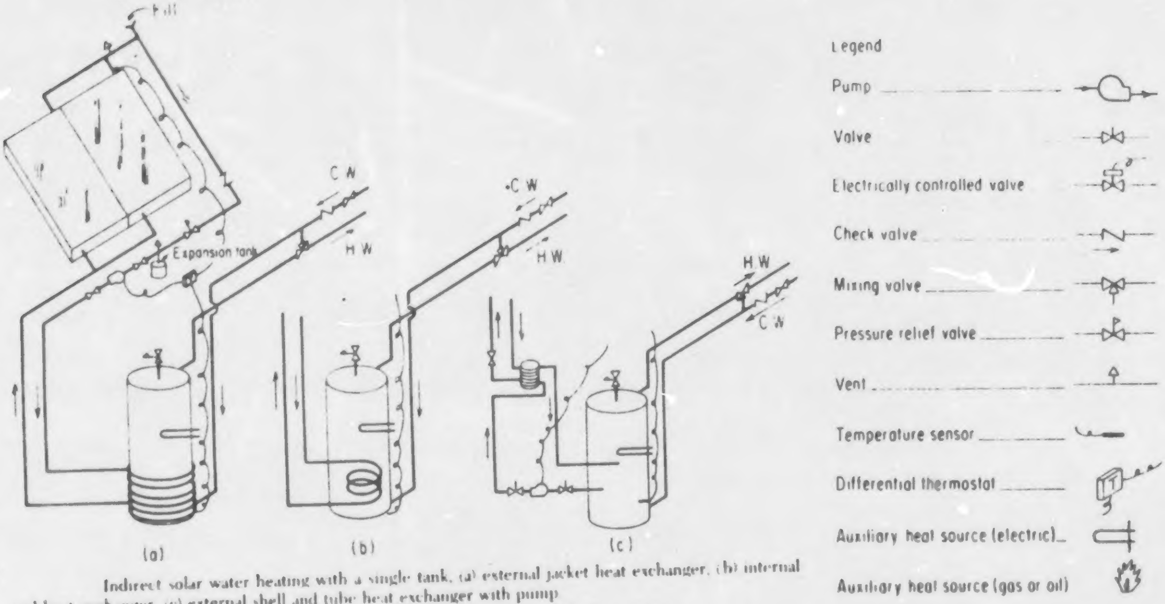


Figure 4-26.

Indirect Systems: A forced-circulation, or pumped, system, may also be an "indirect" system. In an indirect system, a fluid (such as antifreeze, air, distilled water, or an organic heat-transfer fluid) other than the potable or service water, is circulated through the collectors; energy is transferred to the heated water through the collectors; and finally, energy is transferred to the water to be heated through some form of heat exchanger. An indirect system design permits use of a nonfreezing fluid in the collector circuit (or any of the methods available for direct systems) to circumvent the freezing problem, but the required heat-exchange process imposes a system thermal performance penalty - all other factors being equal.

Some common antifreeze solutions used in collectors (and their freezing points) are: 50% water/ethylene glycol (-33° F); 50% water/propylene glycol (-28° F); and silicone oils (-120° F). Antifreeze liquids are used in climates where freezing occurs frequently.

Simple types of indirect domestic hot water systems are shown in Figure 4-27, which appears on the following page. These systems are analogous to the single-tank direct system, except that a heat exchanger is used to transfer solar energy into the lower portion of the tank. Proper design of the heat exchanger is essential to achieving high thermal efficiency. Since temperature stratification in the tank is also important to thermal efficiency, the auxiliary

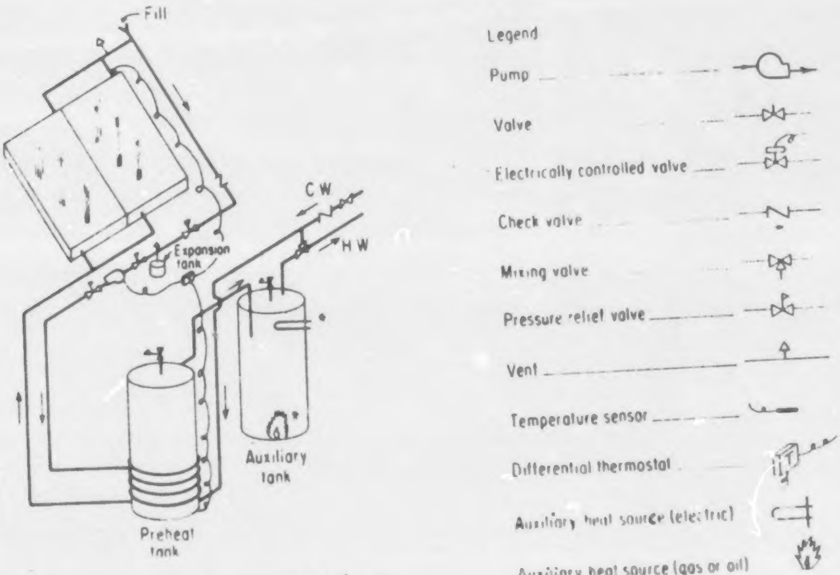

Fill
Expansion tank
C W
H W
(a)
(b)
(c)
Legend
Pump
Valve
Electrically controlled valve
Check valve
Mixing valve
Pressure relief valve
Vent
Temperature sensor
Differential thermostat
Auxiliary heat source (electric)
Auxiliary heat source (gas or oil)

Indirect solar water heating with a single tank, (a) external jacket heat exchanger, (b) internal coil heat exchanger, (c) external shell and tube heat exchanger with pump

Figure 4-27.

element should be placed in the upper part of the tank, precluding the use of oil or gas as a backup energy source.

A two-tank indirect system is shown in Figure 4-28. Although a jacket heat exchanger is illustrated, the internal coil, or external, pumped, shell-and-tube heat exchangers may also be used. The separate auxiliary tank permits use of electricity, oil, or gas as the backup energy source.


Fill
Expansion tank
C W
H W
*
*
Auxiliary tank
Preheat tank
Legend
Pump
Valve
Electrically controlled valve
Check valve
Mixing valve
Pressure relief valve
Vent
Temperature sensor
Differential thermostat
Auxiliary heat source (electric)
Auxiliary heat source (gas or oil)

Indirect solar water heating with a preheat tank and a separate auxiliary tank
* means either auxiliary energy source is acceptable

Figure 4-28.

Drainback Systems: When water is used as the heat transfer fluid, system freeze protection can also be accomplished by using a drainback system, as illustrated in Figure 4-29. The system uses pure water (usually deionized water obtained from a drug store or chemical supply house), and completely drains water from the pipes each time the pump shuts off. The solar heat transfer fluid automatically drains into a tank by gravity, leaving no liquid to freeze in the collectors. A heat exchanger is necessary, because the city water inlet pressure would prevent draining of pipes directly attached to the city's mains. The heat transfer fluid in the collector loop may be distilled or city water if the loop plumbing is copper. If the plumbing is galvanized pipe, an inhibitor may be added to prevent corrosion. Most inhibitors are nonpotable and require a double-walled heat exchanger.

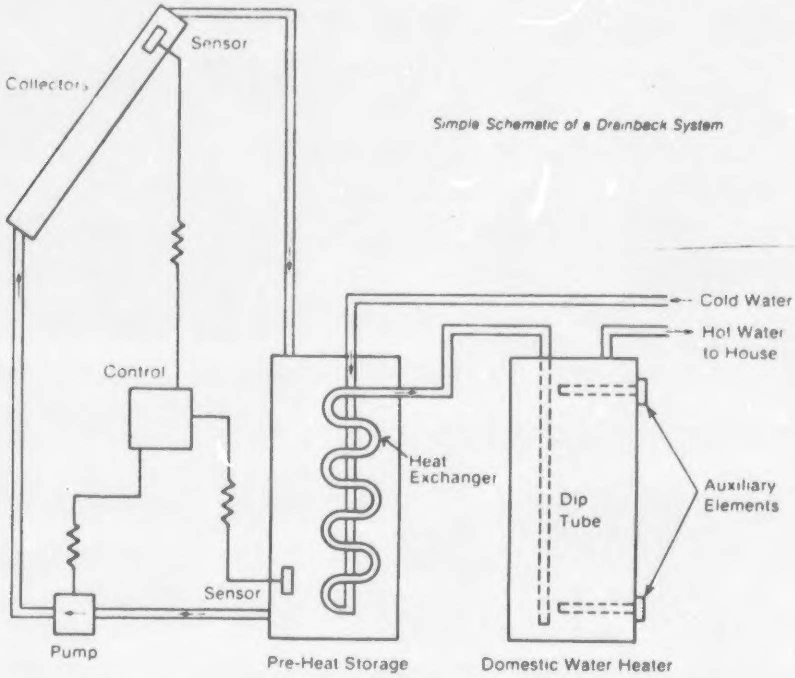

Simple Schematic of a Drainback System
Sensor
Collectors
Control
Cold Water
Hot Water to House
Heat Exchanger
Dip Tube
Auxiliary Elements
Sensor
Pump
Pre-Heat Storage
Domestic Water Heater

Figure 4-29.

Freeze sensing is not necessary because the collectors are void of water except during times when the sun is shining on them. The collector loop is nonpressurized, with water falling back by gravity to the storage tank from the top of the collector loop. Downward pitch of the piping is important in this system, so that water will not remain in the collectors to freeze. Because the drainback system is nonpressurized, a larger pump is required to push the water to the top of the collectors (overcome the system head) before gravity returns the water to the storage tank. The drainback system requires a heat exchanger between the storage tank and delivery to the hot water supply.

A drainback system uses no antifreeze. Its controls are simpler than those for a draindown system, and it offers more efficient heat transfer than do antifreeze systems. Collectors must be positioned above the storage tank so that gravity can drain them for freeze protection. A large heat exchanger is needed in a preheating tank, and a pure water system must be maintained.

Double-Tank Closed-Loop Systems: A two-tank closed-loop system is illustrated in the accompanying Figure, 4-30. This system uses an antifreeze mixture in the collector loop for freeze protection.

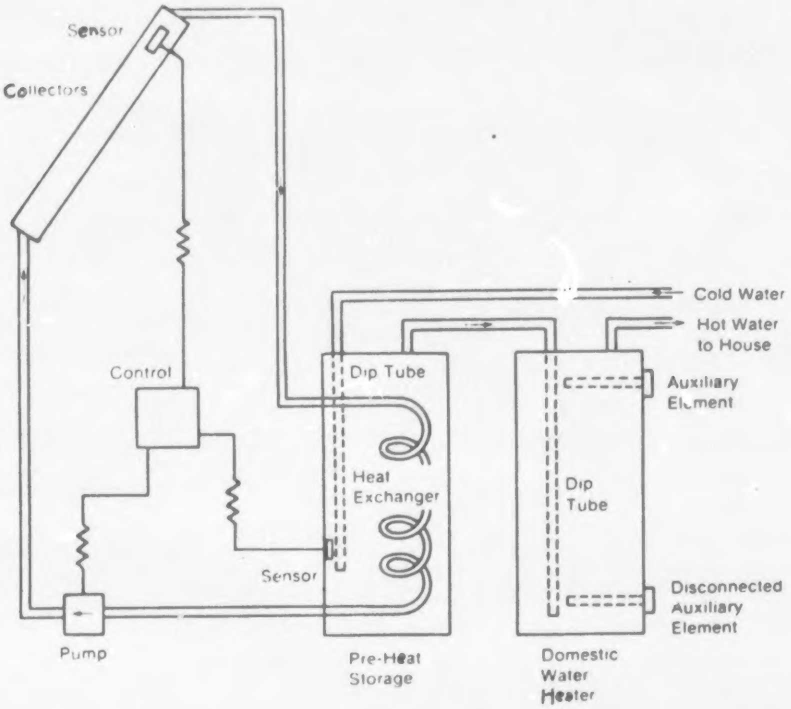

Sensor
Collectors
Control
Cold Water
Hot Water to House
Dip Tube
Auxiliary Element
Heat Exchanger
Dip Tube
Sensor
Disconnected Auxiliary Element
Pump
Pre-Heat Storage
Domestic Water Heater

Figure 4-30: Simple Schematic of Two-Tank Closed-Loop System

Antifreeze systems generally require double-walled heat exchange for consumer protection against toxic fluids. However, not all antifreeze solutions are toxic; state and local codes dictate heat exchange requirements. Greater system efficiency can be expected from a single-walled heat exchanger than from a double-walled one.

The major advantage of a double-tank system, when compared to a single-tank system, is that cooler liquids are brought to the collector, increasing its operating efficiency. Warmer liquids are brought to the collector from a single-tank system, since the back-up heating element is contained in the single tank.

In addition to greater collector efficiency and freeze protection, double-tank systems require a smaller pump than draindown or drainback systems. However, the two tanks and associated plumbing are more expensive; more insulation is required; heat transfer is not as efficient; and extra components such as expansion tank, air eliminator, pressure relief valves and gauges are needed.

Single-Tank Closed-Loop Systems: A single-tank closed-loop system is illustrated in Figure 4-31. This system uses an antifreeze mixture in the collector loop for freeze protection and the back-up heating source is usually electricity. Tank heat losses are less from a single-tank system than from a

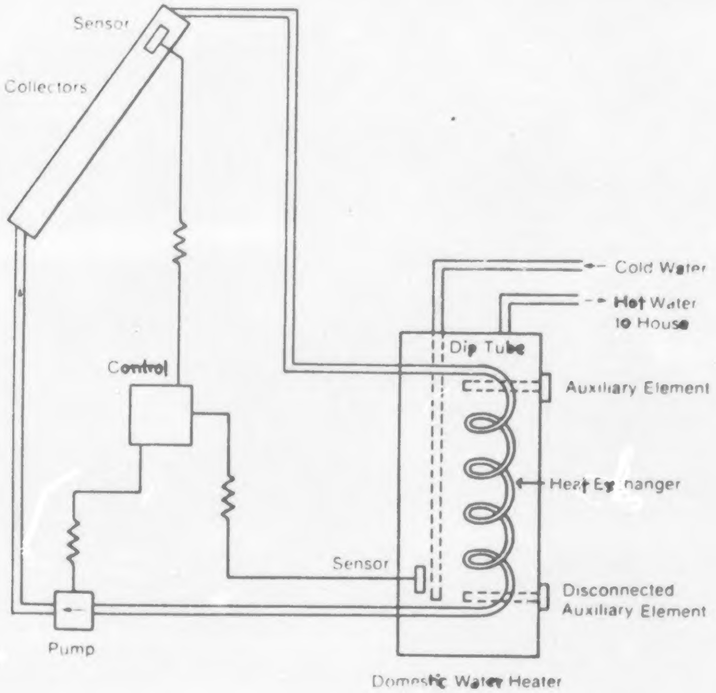

Sensor
Collectors
Control
Cold Water
Hot Water to House
Dip Tube
Auxiliary Element
Heat Exchanger
Sensor
Disconnected Auxiliary Element
Pump
Domestic Water Heater

Figure 4-31: Simple Schematic of a Single-Tank Closed-Loop System

double-tank system. A single-tank system costs less to install and requires a smaller pump than open loop systems. A double-walled heat exchanger may be needed, and this means that heat transfer is not as efficient.

Heat Pump Systems: A type of indirect domestic hot water system which uses an electric pump to extract energy from a combination collector and storage tank is shown in Figure 4-32. The water stored in the collector-tank serves as a thermal sink for the evaporator side of the heat pump. If the collector-tank is designed to permit freezing of the stored water without damage, the heat of fusion available from the ice-making process provides a large thermal-storage effect. This maintains a minimum heat-sink temperature of 32° F for the heat pump, even though the ambient temperature may drop well below freezing for considerable periods of time. Whenever the ambient temperature is above freezing, the collector draws heat from the surrounding air, rain, and moisture condensation as well as by absorbing the incident solar energy.

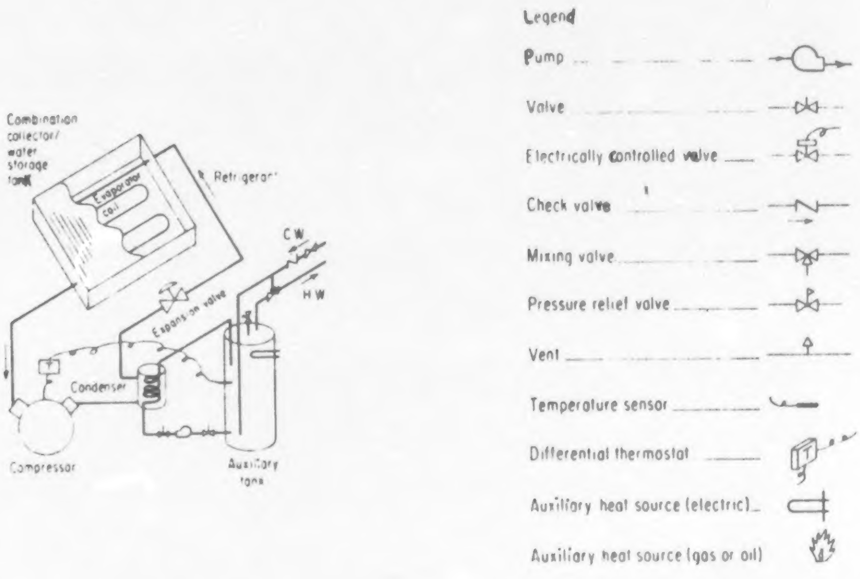

Combination collector/ water storage tank
Evaporator coil
Refrigerant
C W
H W
Expansion valve
Condenser
Compressor
Auxiliary tank
Legend
Pump
Valve
Electrically controlled valve
Check valve
Mixing valve
Pressure relief valve
Vent
Temperature sensor
Differential thermostat
Auxiliary heat source (electric)
Auxiliary heat source (gas or oil)

Figure 4-32: Indirect Solar Water Heating Electric Heat Pump and Combined Collector/Storage Unit which is Permitted to Freeze

Air Systems: Air collectors (i.e., collector loop using air as the heat transfer fluid) for domestic hot water heating can also be used as illustrated in Figure 4-33, a simple diagram of an air system. A fan is used to blow air through collectors. The heated air blows over a large air-to-liquid heat exchanger, through which the domestic water supply is being circulated through the storage tank.

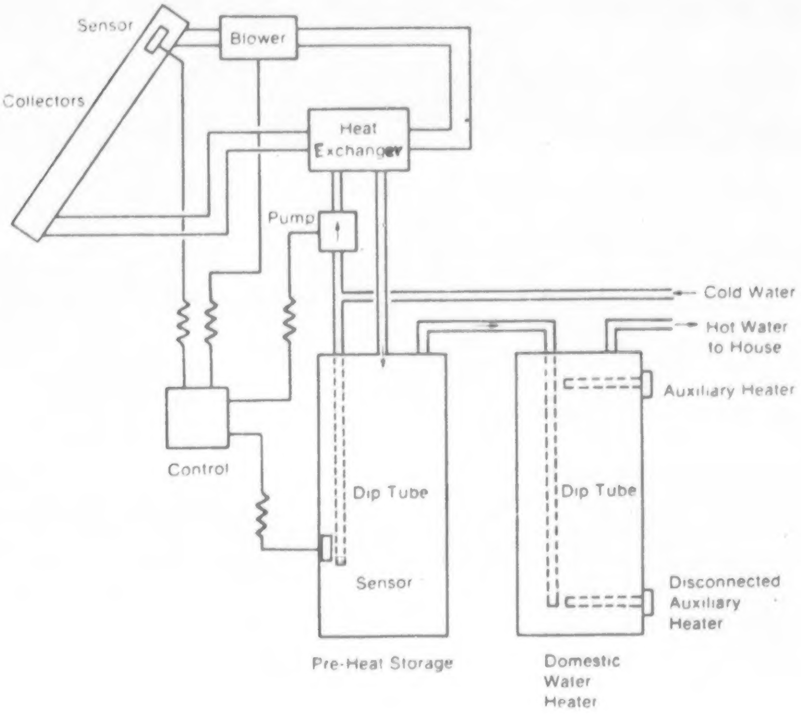

Sensor
Blower
Collectors
Heat Exchanger
Pump
Cold Water
Hot Water to House
Auxiliary Heater
Control
Dip Tube
Dip Tube
Sensor
Disconnected Auxiliary Heater
Pre-Heat Storage
Domestic Water Heater

Figure 4-33: Simple Schematic of an Air System

Air obviously does not need freeze protection, and it is free. Corrosion is not a problem. In general, air systems require less maintenance than liquid systems. However, air ducts and air handling units require greater space than piping used for liquid systems. In addition, air leaks are difficult to detect. Both air fans and liquid pumps are required for the air system.

This concept may be used either with a single stratified tank or with separate preheat and auxiliary tanks as illustrated.

The use of air in the collectors and outside ducting eliminates the potential hazards of contamination of potable water with antifreeze or other nonfreezing heat-transfer liquids.

The reduced efficiency of air as a heat-transfer fluid compared to liquids, however, will typically require a greater collector area to achieve a given level of thermal performance than would be needed in a well-designed liquid system.

Using Solar Domestic Hot Water

Solar water heaters are the most popular way to use solar energy and the most economical at present to install. Tax incentives were written into law in late 1978, giving the homeowner a maximum income tax credit of $22 for installing solar or other renewable energy sources in the home.

Solar water heaters are competitive today in areas where electric water heaters must be used. Up to 17% of a home's energy consumption is for heating water. If it is heated by electricity at a price of 4¢ per kilowatt-hour, the monthly water heating bill is about $20 to heat 100 gallons of water per day. If a solar system will serve the family with 80% of its hot water needs, and the conventional electric hot water heater serves the remaining 20%, the monthly bill could be reduced $16 per month. Calculating a 30-year mortgage on a $1400 solar system, the resulting savings will be $4 per month.

Therefore, a solar water heating system might be considered. If, however, water is heated with natural gas at a price of 17¢ per day (the average cost for 100 cubic feet of gas, which typically heats 100 gallons of water per day), the bill will be about $5.17 per month. This is much cheaper than solar. Deregulation of natural gas and escalating prices could change this situation and make solar energy more competitive with natural gas.

A solar water heating system can cost less than $1000 if some of the work is done by the homeowner. Most systems, however, cost between $1800 and $2100 - installed. With the annual increase in electricity rates estimated at 4%, a solar water heating system that lasts 20 years and costs $1000 could repay itself in 10 years or less, giving "free" hot water for the remainder of the system's life.

A solar water system does not replace a conventional hot water system - it only supplements it. A solar system is capable of providing water at 115° to 165° F, depending on the cloud conditions and outside temperature. Therefore, the solar water system might serve as a preheat for conventional water heating systems requiring gas or electricity, to bring up the water temperature to the desired temperature.

Advantages and Disadvantages: Solar hot water systems work well. Water is a cheap and efficient heat transfer and storage medium. Piping uses little space, is easily interconnected, and can be routinely routed around corners or to remote places. Active solar energy is quickly becoming cost competitive where electricity or oil are being used to heat water for residences.

Cost reduction is an important advantage of solar domestic hot water systems. How quickly the system will pay for itself depends on:

1. The proportion of conventional energy saved;
2. The present and future price of the fuel being displaced;
3. The purchase and maintenance costs of the system;
4. The expected system life;
5. The financial incentives available;
6. The possible increase in property value;
7. Family use of energy to take best advantage of solar energy.

On the negative side, initial cost of the system is comparatively high, although federal tax incentives of 40% (plus frequently available state tax credits, where appropriate) are a major help with this problem. Care must be taken to prevent corrosion, scaling, or freezing capable of damaging or clogging the system. Leakage anywhere in the system can damage both it and the dwelling. Contamination of the hot water is possible if a leak allows the heat transfer fluid (other than water) to enter the domestic water system.

Points to Consider: After reviewing the kinds of solar water heating equipment available, the anticipated life-cycle cost of the systems compared to present fuel costs, and the intended use for the system, consult with a designer, installer or engineer who has solar experience. Also, keep in mind that the most economical installation is with new structures.

More attention is being given to solar. It is important to weigh all facts before investing in it. The National Solar Heating and Cooling Information Center makes the following suggestions for consideration when buying solar equipment:

1. Ask for proof that the product will perform as advertised. An independent laboratory or university report should be consulted.

2. Examine the warranty carefully. According to law, the manufacturer must state whether the warranty is full or limited. Ask the seller what financial arrangements, such as escrow account, have been made to honor the warranties.

3. Solar components should work well together. If the system you are buying is not sold as a single package by one manufacturer, be sure that the seller has experience in choosing compatible components.

4. Be sure you will know specifically who will service the solar system if anything goes wrong - not just any plumber or tinkerer can do the job.

5. Don't try a do-it-yourself kit unless you really have a solar background as a repair person.

6. Check with your local consumer office or Better Business Bureau to determine whether the seller is reputable.

7. If the seller makes verbal claims that are not reflected in the literature handed out, have the claims written down and have the seller sign the statement.

8. If you have what appears to be a legitimate complaint, notify the local District Attorney's office.

CONSERVING WATER

Personal Hygiene

Energy Savings Tips For Hot Water Use: Personal hygiene requires large amounts of hot water - approximately 33% of daily water use. It takes about 30 gallons of water to fill the average bathtub. A shower with a flow rate of 4 gallons of water a minute used only 20 gallons in 5 minutes. If the shower uses half hot and half cold water, this would be a savings of 5 gallons of hot water by showering instead of bathing. By substituting just one shower for one bath a day, there could be a savings of almost 2000 gallons of hot water a year. If a flow reducing shower head were installed, cutting the flow rate to 2 gallons of water per minute, this savings could double. In a family of four, a flow reducing shower head, which costs $20 and reduces the flow rate to 2 or 3 gallons of water per minute, could pay for itself in 3 to 4 years.

Try bathing one after the other so that there will be full utilization of hot water stored in hot water pipes. Limit the shower to five minutes so that as little water as possible will run unnecessarily. Consider taking a shower by wetting the body, turning off the water while soaping, then turning the water back on to rinse. This can be done with some shower controls or with thermostatic mixing valves. These devices automatically mix hot and cold water to a desired temperature, so that when it is turned off, then back on again for rinsing the temperature will remain the same. This method of showering can save 10-40% of the warm water used in showers, but the costs of thermostatic mixing equipment is two or three times the price of conventional equipment. This should be taken into consideration before purchase.

When shaving, or rinsing items in a sink, fill the sink with water instead of permitting the faucet to run needlessly in an open sink. Do not permit the faucet to run until the water is the desired temperature before plugging the drain. Plug the drain at the beginning, thus capturing the 3 to 5 gallons of water that flow before hot water reaches a bathtub or sink.

Water Conservation: Other saving tips for use of water in personal hygiene include the following:

1. Repair dripping faucets; leaks can lose up to 400 gallons of

water a day.

2. Do not leave water running needlessly; turn off water while brushing teeth or shaving.

3. Install water flow reducers in showers and faucets.

4. Limit the time in a shower; a 5-minute shower can use up to 60 gallons of water.

5. Time each shower; unless it can be completed in 4 minutes, a bath might use less water.

6. For baths, fill the tub only one-fourth fill.

Kitchen-Laundry

Energy Savings Tips for Hot Water Use: Twenty-five percent of household water is used in the kitchen and laundry. Most of the appliances requiring hot water are located in these two areas.

In the kitchen, use cold water rather than hot to operate a food disposer. Use cold water instead of hot water for rinsing vegetables and preparing food. Use a reduced flow rate device on slow settings for routine rinsing. Do not waste hot water rinsing dishes before putting them in the dishwasher; just scrape them off and put them in the dishwasher. When handwashing dishes, first soak them in detergent to loosen baked-on food and rinse them sparingly. Be sure to use the dishwasher for full loads only. Avoid the extra-long, prewash, and soak cycles on the dishwasher unless absolutely necessary. This can save 3 to 7 gallons of hot water each time. Experiment with shorter cycles and less detergent to save on hot water.

Use cold water for washing clothes whenever possible. With many of the detergents on the market, as clean a wash as one in hot water will result. If hot water is used, consider having the hot water tank near the washer, so that heat in the pipes will not escape needlessly.

There are two water-saving features built into many of the new automatic washing machines. One is the water level control. The variable water level control allows the level of the water flowing into the washing machine to be regulated to the appropriate washing need - a low-level setting for small wash loads, and medium, large, and extra-large settings or graduatingly larger loads.

Another feature is the suds-saver. This device allows the hot wash water plus detergent to be drained into a laundry tub for re-use in the next wash load. This saves heating a second load of wash water. This device features a 20-gallon reservoir which drains into a nearby utility sink; when the second load of wash is put into the washer, the tub is filled from this reserve. Though the cost of the device is only $15 to $20, the expense of installing a nearby utility sink may be more expensive than savings realized from re-usable hot water.

Sort clothes before washing. This will help determine load sizes and will help group items which require certain water temperatures. Even if a load of clothes must be washed in hot water, it is not necessary to rinse them in hot water. Wash loads consecutively if possible to take advantage of the machine being warm.

Water Conservation: Other saving tips for use of water in the kitchen and laundry include the following:

1. Do not use garbage disposals. They waste water and energy to operate. They chop solid garbage, mix it with water, and send it to a treatment plant where money and energy are spent to remove the garbage from the water.

2. Install an aerator in the kitchen faucet. This reduces the volume of water flowing, but it is hardly noticeable.

3. Save laundry rinse water to put on the garden or lawn, in compost, or to wash the car.

4. Pre-soak or use a soak cycle when washing heavily soiled clothes. This will avoid a possible second washing.

Waste Disposal

Toilet: The major use of cold water in the home is the toilet, which accounts for about 40% of a city's water use. Tank-type toilets normally consume between 5 and 8 gallons of fresh water per flush to sweep away less than a pint of waste. This can be reduced by 3 to 3-1/2 gallons by installing new water-saving toilet tanks. These are designed to give full flushing action but reduce the water requirement to about 3 gallons per flush. It may not be economically feasible to replace present fixtures with these new ones since they are fairly expensive. There are some measures which can be taken with a conventional tank, however. Consider putting bricks or water-filled bottles in the tank to displace a certain amount of water. This will allow the tank to fill to its normal level - minus the space displaced by the bricks. Another method is to adjust the float so that the tank does not fill to its original level. This does not work well since the tank must build certain pressure from the height of the water line, in order to flush properly. One drawback of these devices is that it may take two flushes adequately to rid the toilet of waste; this would cancel any water saving benefits. Several commercial products are available as tank inserts and special flush valves which are inexpensive.

Another consideration for toilets is the number of waterless units available on the market. These include compost toilets, which compost toilet wastes as well as kitchen scraps. Other units include chemical recirculating toilets, incineration toilets, and grey water systems for large housing projects. Grey water is defined as recirculated, non-potable water.

Outdoors: Be conservative with outdoor water use. This does not mean stop watering the lawn, but become conscious of ways better to utilize water for this purpose. The impact of energy savings on outdoor watering is not as great as on indoor use, because the water does not enter the sewage system. However, many homes use a great deal of water outdoors - over 200,000 gallons on lawns with automatic sprinklers, for instance. Plant ground covers such as ivy or iceplant instead of lawn grass because they take less water. Water in the mornings or late evenings when temperatures are not high, in order to cut down on evaporation. Time watering periods. Locate sprinklers so that they do not spray sidewalks, the house, or run down driveways into the curb. When washing a car, use a self-closing nozzle on the hose so that the water can be closed off while soaping the car.

Water Conservation: Other saving tips for use of water in waste disposal include the following:

1. Reducing flushing toilets whenever possible.
2. In warm weather, wash the car during a rain - if there is no lightning.
3. Let the rain water the garden. In a dry spell, give plants one soaking per week in the early morning or late evening.
4. Collect rain in a barrel or cistern for use around the house.
5. Remember, the philosophy of using any resource is using it effectively. This does not mean doing without; it means getting the most from the energy or the resource spent.

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ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

ILLUMINATION, APPLIANCES AND ENERGY CONSERVATION

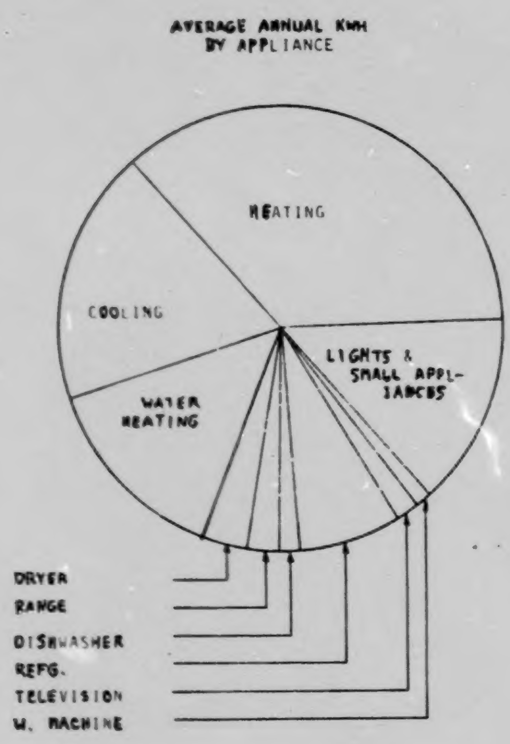
STUDENT MATERIAL

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

ILLUMINATION, APPLIANCES AND ENERGY CONSERVATION

INTRODUCTION

Approximately 8% of the homeowner's energy usage is to operate electrical home appliances. Electricity for home appliances ranks third in the homeowner's energy use, behind home space heating and cooling and water heating. Heating and cooling a home accounts for 70% of the homeowner's energy use, while water heating accounts for another 20% (see Figure 5-1).



SOURCE: TEXAS POWER & LIGHT COMPANY

Figure 5-1

The quality of energy consumed for these purposes depends on many factors, but the average is about 7500 kilowatt hours (KWH) of electricity for a four-person family. Of this total, the refrigerator consumes about 22%; the range, 14%, dishwasher, 4%; clothes washer, 2%; dryer, 12%; TV, stereo and miscellaneous, 23%; and lights, 23%. See Figure 5-2.

The corresponding costs for appliance and lighting energy vary throughout the country. In New York, at 9¢ per KWH, the annual bill would be over $675! At a more average rate of 4¢, the bill would still be about $300.

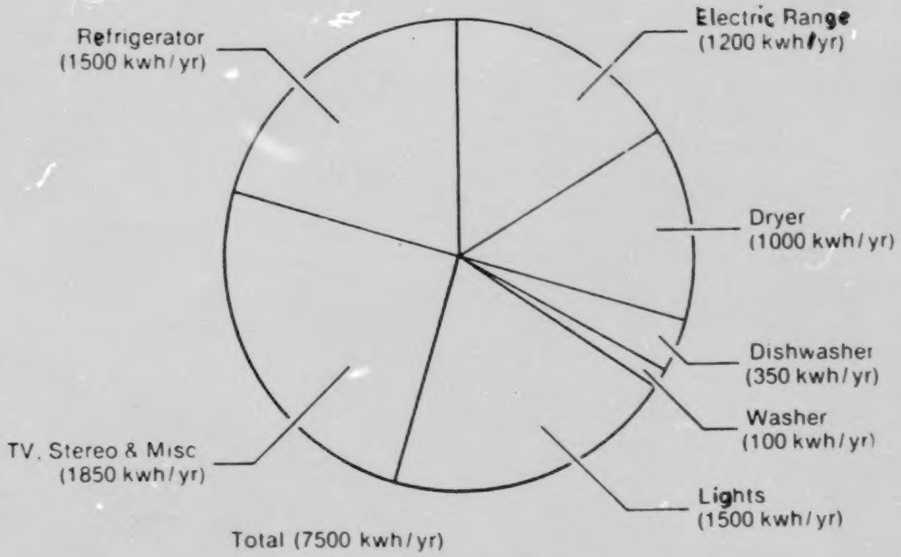


Figure 5-2: Appliance and Lighting Energy For A
Typical Four-Person Family

ELECTRICAL APPLIANCES

Appliances now in use are larger and more sophisticated than those of the past. Compare, for instance, the size of refrigerators 20 years ago to the size of refrigerators today. Today's refrigerators are built larger, have more features, and, consequently, use more energy. The two major uses of appliances in the home - after heating, cooling, and water heating - are for refrigeration and food preparation or cooking. When purchasing one of these major appliances, the customer should select a size to meet household requirements. Once purchased, care should be taken to keep the appliance maintained and in top working order.

The amount of energy used by appliances varies among type, brand and size of appliances; geographic area of use; and the individual use of the appliance. The key to determining the amount of energy an appliance uses is in the wattage of that appliance. An appliance with a wattage rating of 1,000 uses one KWH of electricity for every hour it is in operation. Figure 5-3 shows how much electrical energy an appliance uses in one hour of operation at various wattage ratings, and the approximate amount of oil or coal burned at the power station to produce that amount of electrical energy. By multiplying the customer's cost of one kilowatt of electricity by the KWH of energy used per hour, the cost of one hour's operation can be determined for any appliance in the home.

ELECTRICAL APPLIANCE ENERGY TABLE

APPLIANCE WATTAGE RATING	KILOWATT-HOURS OF ENERGY USED PER HOUR	OUNCES OF OIL BURNED PER HOUR	OUNCES OF COAL BURNED PER HOUR
10	1/100	1/10	13/100
25	1/40	1/4	33/100 (OR 1/3)
40	1/25	2/5	1/2
60	3/50	3/5	4/5
100	1/10	1	1-1/3
150	3/20	1-1/2	2
200	1/5	2	2-2/3
300	3/10	3	4
500	1/2	5	6 2/3
700	3/4	7-1/2	10
1000	1	10	13-1/3
1500	1-1/2	15	20
2000	2	20	26-2/3
5000	5	50	66-2/3

SOURCE: THOMAS ALVA EDISON FOUNDATION

Figure 5-3

Comfort Conditioning Appliances

Since the type and size of comfort conditioning equipment is widely varied, electrical consumption differs greatly from one installation to another.

Table 5-1 below lists a sampling of comfort conditioning household appliances, and the estimated KWH consumed monthly in using the appliance.

COMFORT CONDITIONING	AVERAGE WATTAGE	EST. KWH CONSUMED HOURLY
AIR CLEANER	50	.05
AIR CONDITIONER (ROOM) 12,000 BTU	1,600	1.6
BED COVERING	177	.177
DEHUMIDIFIER	257	.257
FAN (ATTIC)	370	.370
FAN (CIRCULATING)	88	.088
FAN (ROLLAWAY)	171	.171
FAN (WINDOW)	200	.200
FURNACE FAN	500	.500
HEATER (PORTABLE)	1,322	1.322
HEATING PAD	65	.065
HUMIDIFIER	177	.177

Table 5-1.

Food Preservation Appliances

The wattage and consumption of freezers and refrigerators vary according to make and size. Additionally, the electrical consumption is affected by many variables; family size, usage, environment, etc.

Table 5-2 lists a sampling of food preservation household appliances and the estimated KWH consumed monthly in using the appliance.

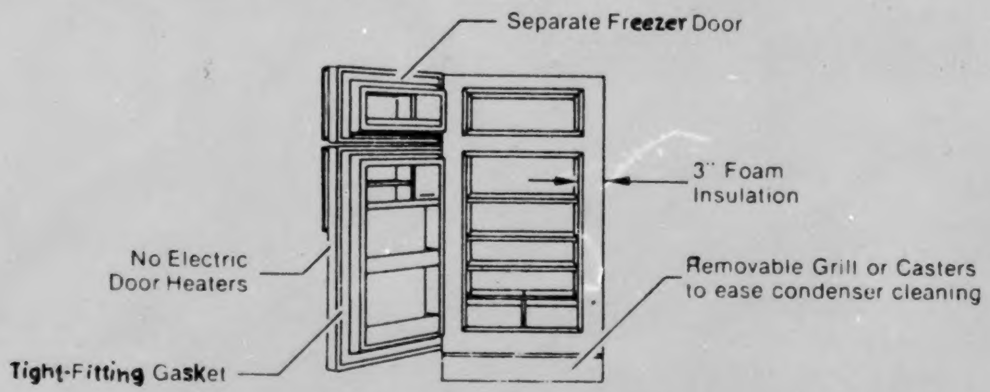
FOOD PRESERVATION	AVERAGE WATTAGE	EST. KWH CONSUMED MONTHLY
FREEZER (15-21 FT.)		
CHEST TYPE, MANUAL DEFROST	-	110
UPRIGHT TYPE		
MANUAL DEFROST	-	110
AUTOMATIC DEFROST	-	165
REFRIGERATORS/FREEZERS		
MANUAL DEFROST, 10-15 CU. FT.	-	58
AUTOMATIC DEFROST, 16-18 CU. FT.	-	150
AUTOMATIC DEFROST, 20 CU. FT. & UP	-	158

Table 5-2.

Refrigerators: A number of manufacturers now advertise energy-saving refrigerator models with many good features. The energy savings for these models are between 30 and 50%!

The most important energy-saving feature to look for is more insulation. Conventional refrigerators have only about one inch or so of fiberglass insulation in the sides, top, bottom, and door. There are no technical reasons why two to three inches of foam insulation, which is superior to fiberglass, cannot be used instead. The only problem is that the refrigerator will be a little larger on the outside for a constant inside volume, and it will cost more. Generally, though, the extra first cost will be saved by lower operating costs in three to four years.

In addition to more insulation a number of other key features are worth checking out. Refrigerators should have a separate freezer-section door so that you don't have to open up and, consequently, warm the refrigerator to get at the freezer. Manual defrost units, when properly cared for, use 20 to 40% less energy than self-defrosting models. Options like ice makers and water coolers consume energy and are hard to service. Casters and removable grills make cleaning the condenser easier, which is important to keep the unit at top efficiency. Doors should always have tight-fitting gaskets to prevent air leakage. Finally, stay away from refrigerators with electric door heaters. See Figure 5-4 for features you should look for when selecting a refrigerator.



CONSTRUCTION FEATURES
OF AN ENERGY SAVING REFRIGERATOR

Figure 5-4

Make sure that refrigerator doors close and seal properly. You can check this by closing the door on a piece of newspaper. If the paper pulls out easily, you need a new gasket. Also, keep the condenser on the back of the refrigerator clean, so it can operate efficiently.

One of the greatest sources of wasted electricity in a refrigerator or freezer is allowing frost to collect on the evaporator unit. When excessive frost accumulates, the appliance must run for longer periods of time to cool food. This results in wasted energy.

Defrosting should be done before the ice builds up to more than 1/2 inch. Manual defrosting is not an easy chore, but should be done periodically to prolong the life of the refrigerator, and to cut down on energy use.

Frost-free refrigerators and freezers use more energy for this time-saving feature, but eliminate the task of defrosting manually. Frost-free units have an automatic time clock which periodically turns the cooling unit off and turns on heater strips to melt the ice build-up on the evaporator coils. The heater remains on long enough to melt the frost and ice, which then drains into a pan under the condenser.

The refrigerator should be set on 38° F to 40° F for the refrigerator compartment, and 5° F for the freezer section on a refrigerator/freezer combination. Lower settings waste energy by increasing frost build-up; higher settings will save energy but will not keep food properly, thus defeating the purpose of the refrigerator. Separate freezers used to keep food for long periods of time should be set at 0° F.

Keep the condenser well ventilated and clean from dirt and lint build-up. The condenser coil located at the back or on the bottom of the unit allows heat to escape the refrigerator unit. Dust accumulation reduces this condensation and interferes with heat transfer from the coils into the surrounding air. Clean these coils at least twice a year. This could save as much as $1.00 a year on refrigerator operating costs.

Do not block the condenser coils by restricting air circulation. Place the unit away from the wall with no cabinet overhang to interfere with condenser coil fans or air circulation.

A recent feature introduced on refrigerators and freezers is the power-saver switch. Most refrigerators have heating elements in the walls or doors to prevent sweating or humidity build-up on the outside. In most climates, the heating element does not need to be working all the time. The power-saver switch turns off the heating element in dry climatic conditions. By using the power-saver switch, 16% of refrigerator energy costs can be saved.

Another item which needs consideration for efficient operation for a refrigerator or freezer is proper wiring. A freezer or refrigerator requires a great deal of electrical current when it first starts up. This sudden surge of power is usually three to four times as much as is required when it is running. Refrigerators require 15 or 20 amp circuits to prevent the brief surges of power from blowing a fuse or circuit breaker. In addition to providing proper circuits, only one large appliance should be plugged into a single circuit. When two or more large appliances - refrigerators, freezers, toaster ovens, irons, grills, microwave ovens - are plugged into the same circuit, the efficiency of each can be reduced greatly and the energy usage strained. This results in each motor working harder for longer periods of time, which shortens the life of the motor. The cord on a freezer or refrigerator is seldom longer than five or six feet. If an extension cord must be used, be sure to use a heavy-gauge cord. Most inexpensive extension cords are made of 16-gauge wire, which is too small for large appliances. Even 14-gauge wire is too small, if the distance from outlet to unit is more than 10 feet. Therefore, it is recommended that 12-gauge wire be used for appliances, if the extension cord is longer than 10 feet, and that 14-gauge wire be used for shorter distances. Always use grounded wire and outlets, to prevent possible shock.

Food Preparation Appliances

Table 5-3 below lists a sampling of food preparation household appliances and the estimated KWH consumed monthly in using the appliance.

HOUSEHOLD APPLIANCES

FOOD PREPARATION	AVERAGE WATTAGE	EST. KWH CONSUMED MONTHLY
BLENDER	300	0.1
BROILER	1,140	7
CARVING KNIFE	92	0.1
COFFEE MAKER	1,000	1.0
CREPE MAKER	894	9
DEEP FRYER	1,448	7
DISHWASHER (2 LOADS)	1,201	30
DOUBLE HAMBURGER MAKER	750	.75
EGG COOKER	516	1
FOOD PROCESSOR	360	.17
FRYING PAN	1,196	8
HOT PLATE	1,200	8
MIXER	127	0.2
OVEN, MICROWAVE (ONLY)	1,450	16
RANGE		
WITH OVEN	12,200	98
WITH SELF-CLEANING OVEN	12,200	100
ROASTER	1,333	5
TRASH COMPACTOR	400	2
WAFFLE IRON	1,200	2
WASTE DISPENSER	445	2

Table 5-3.

Ranges: Since energy consumption for ranges is fairly evenly distributed between the cook top and oven, conservation efforts must be aimed at both for maximum savings. Electric range cook tops should have "calrod" surface elements for good thermal contact with the bottom of pots and pans. Ceramic cook tops suffer in this regard and should not be considered. All ovens should be well insulated. Manufacturers have not got the message yet and provide high insulation only on certain types of self-cleaning ovens, the "pyrolytic" or high-temperature type. The difference in insulation is about 50%; conventional ovens have about 1-1/2 inches of fiberglass, while the "pyrolytic" units have about 3 inches. The best bet is to choose a "pyrolytic" oven and then use the self-cleaning feature sparingly until well-insulated, manual clean ovens are available.

Gas ranges have a similar problem with lack of insulation - so, again, get one with a self-cleaning feature and use it wisely. Gas cook tops, however, all have about the same burner efficiency, so there is little to choose from. The best opportunity for energy conservation is to buy a range with an electronic igniter. This feature substitutes for the pilot lights (there are three of them in most ranges) and can save about 30% of the annual gas consumption. "Caloric" gas ranges are the only ones with this feature right now, but other manufacturers should also be offering it soon.

Other ways to save cooking energy are to use efficient cooking utensils and special-purpose appliances. A pressure cooker, for example, can cut cooking time for boiled foods in half. Electric fry pans and toaster ovens can be used for small meals, instead of heating up the main oven. Microwave ovens certainly offer large energy savings, but they should not be used by people with heart pacemakers, as this can be dangerous.

Cooking: The Department of Energy has outlined several tips and energy saving ideas for cooking.

Use cold water rather than hot to operate a food disposer. This saves the energy needed to heat the water, is recommended for the appliance, and aids in getting rid of grease. Grease solidifies in cold water and can be ground up and washed away.

Install an aerator in the kitchen sink faucet. By reducing the amount of water in the flow, less hot water will be used, and you save the energy that would have been required to heat it. The lower flow pressure is hardly noticeable.

When needing to purchase a gas oven or range, look for one with an automatic (electronic) ignition system instead of pilot lights. An average of up to 47% of your gas use - 41% in the oven and 53% on the top burners - will be saved.

If using a gas stove, make sure the pilot light is burning efficiently - with a blue flame. A yellowish flame indicates that an adjustment is needed.

Never boil water in an open pan. Water will come to a boil faster and require less energy in a kettle or covered pan.

Keep range-top burners and reflectors clean. They will reflect the heat better, and thus save energy.

Match the size of pan to the heating element. More heat will get to the pan; less will be lost to surrounding air.

If cooking with electricity, get in the habit of turning off the burners several minutes before the allotted cooking time. The heating element will stay hot long enough to finish the cooking without using more electricity.

When using the oven, make the most of the heat from that single source. Cook several foods at one time. Prepare dishes that can be stored or frozen for later or make all oven-cooked meals.

Watch the clock or use a timer; don't continually open the oven door to check food. Every time the door is opened, heat escapes, and your cooking takes more energy.

Use small electric pans or ovens for small meals rather than the kitchen range or oven. They use less energy.

Use pressure cookers and microwave ovens, if owned. They can save energy by reducing cooking time.

Dishwashers: The average dishwasher uses 14 gallons of hot water per load. Since the hot water supplied by the home hot water heater is rarely hot enough to sterilize the dishes, a heating element is built in to heat the water to approximately 130° F. After the dishes have been washed and rinsed, this heating element is used to dry the dishes. This means a dishwasher costs the customer twice: once to heat water in the hot water tank, and once in the dishwasher itself to heat the water to a temperature for sterilization. It becomes very important to utilize this appliance efficiently by monitoring its use, and insuring that it is in good working order.

When installing the dishwasher, size the electric wire properly with the current requirements, as discussed above for refrigerators and freezers.

Insure that hose and water connections are the proper size for the unit so that undue stress and strain on cycle operation does not occur. Proper fittings will reduce wear and prolong the life of the machine.

Clean the food screen often to avoid unnecessary drain clog. If the drain becomes blocked, the motor may overheat, causing serious problems.

The average dishwasher uses 14 gallons of hot water per load, so use it energy-efficiently.

Be sure the dishwasher is full but not overloaded when it is used.

When buying a dishwasher, look for a model with air-power and/or overnight dry settings. These features automatically turn off the dishwasher after the rinse cycle. This can save up to one-third of total dishwashing energy costs.

Let dishes air dry. If the machine doesn't have an automatic air-dry switch, turn off the control knob after the final rinse. Prop the door open a little, and the dishes will dry faster.

Avoid using the "rinse-hold" cycle. It uses 3 to 7 gallons of hot water each time.

Scrape dishes before loading them into the dishwasher, to eliminate rinsing. If rinsing is necessary, use cold water.

If every dishwasher user in the country cut out just one load a week, almost 15 million KWH of electricity could be saved every day, or the equivalent of about 9,000 barrels of oil a day.

Laundry Appliances

Table 5-4 lists a sampling of laundry household appliances and the estimated KWH consumed monthly in using the appliance.

LAUNDRY	WATTAGE AVERAGE	EST. KWH CONSUMED MONTHLY
Clothes Dryer (8 loads per week)	4,856	83
Iron (hand)	1,100	5
Washing Machine (automatic)	512	9
Washing Machine (non-automatic)	286	6
Water Heater	4,500	300-500

Table 5-4.

Clothes Washers: The washing machine is an important appliance to the American family. It uses both hot water and electricity when it operates, and can waste energy needlessly if the water supply is clogged or if the motor is not properly adjusted.

Periodic inspections or routine maintenance can prolong the life of a washing machine and insure that it is operating most efficiently. Check the motor about once a year. Look for broken or cracked V-belts, defective electrical wiring, oil leaks, and loose connections. Check the hoses and drains to make sure they are not crimped or cracked, and are properly tightened. Unscrew the connecting hoses and clean the hose screens of rust particles, dirt, and other obstructions. Remember, a washing machine vibrates during its cycle. This vibration could cause something to work loose and cause it to operate at less than full efficiency.

There are everyday measures to take in using washers which will yield energy savings. First, be conservative with hot water. Second, use the water less frequently by combining or saving up small loads of laundry and making them into larger loads. The Department of Energy suggests other energy saving tips:

Considerable amounts of energy can be saved in the laundry through conservation of hot water and by using automatic washers and dryers less often and more efficiently.

Wash clothes in warm or cold water, rinse in cold, thus saving energy and money. Use hot water only if absolutely necessary.

Fill washers (unless they have small-load attachments or variable water levels), but do not overload.

Use the suds-saver if the washer has this feature. It will allow use of one tubful of hot water for several loads of clothes.

Don't use too much detergent. Follow the instructions on the box. Oversudsing makes machines work harder and use more energy.

Pre-soak or use a soak cycle when washing heavily soiled garments. Avoid two washings and save energy.

Clothes Dryers: Clothes dryers are either all-electric or gas with an electric motor. The purpose of the dryer is to evaporate the water held in wet clothes. This is done by air passing over the clothes and out the vent. Electric dryers use a heating element to warm the air drawn into the dryer. Gas dryers use heated exhaust gas, ignited by an electric spark or hot-wire starter, to dry the clothes. A series of thermostats monitor the temperature of the air entering and leaving the dryer controls. Some dryers have an electronic humidity sensor which determines when the clothes reach a desired amount of dryness. This sensor controls the temperature of the dryer so the clothes will not wrinkle.

Once the moisture has evaporated from the clothes, the dryer will be wasting energy if it is allowed to continue operating. The timer should be set to coincide as closely as possible with the actual amount of time required to dry the clothes.

Clothes dryers often have several drying temperatures and a variety of time settings for various materials. The correct combination of time and temperature setting for certain fabrics gives the most efficient use of the required energy. To accomplish this requires practice and some experimenting.

Below are some energy saving tips for efficient operation of clothes dryers:

Fill clothes dryers but do not overload.

Keep the lint screen in the dryer clean. Remove lint after each load. Lint impedes the flow of air in the dryer and requires the machine to use more energy.

Keep the outside exhaust of the clothes dryer clean. Check it regularly. A clogged exhaust lengthens the drying time and increases the amount of energy used.

If the dryer has an automatic dry cycle, use it. Overdrying merely wastes energy.

Dry clothes in consecutive loads beginning with a load requiring the hottest setting. Stop-and-start drying uses more energy because a lot goes into bringing the dryer up to the desired temperature each time you begin.

Separate drying loads into heavy and lightweight items. Since the lighter ones take less drying time, the dryer doesn't have to be on as long for these loads.

If drying the family wash takes more than one load, leave small, lightweight items until last. You may be able to turn off the power and dry them with heat retained by the machine from earlier loads.

Save energy by using the old-fashioned clothesline. As a bonus, clothes dried outdoors often seem fresher and cleaner than those taken from a mechanical dryer.

The best way to dry clothes is to do it outdoors. A simple rope clothes line costs about $2 and can save $10 per year, as well as give your wash that fresh-air smell. When a dryer must be purchased, it should have a moisture-sensing shut-off control and an adjustable thermostat. With these features, the heater is not on full blast all the time; heat is supplied only when the clothes are damp. The savings are on the order of 10 to 15%.

Although dryers are normally vented to the outdoors, a simple bypass damper plus an extra lint filter will allow the warm dryer exhaust to help heat the house in the winter. If this is added, the pressure drop for the damper and filter should not exceed the maximum recommended for the dryer. If it does, damage to the heating element could occur.

Clothes dryers should be run just long enough to dry the clothes. Often they run 10 to 15 minutes longer than necessary. When weather permits, dry clothes outdoors.

Minor Appliances

The appliances discussed up to this point have been major appliances which serve a necessary function in the home. The energy saving tips have included maintenance for efficient operation and selective use. In addition to major appliances, there are approximately 30 small electric appliances which make the work at home convenient.

The accompanying Table, 5-5, lists a sampling of other household appliances and the estimated KWH consumed monthly in using the appliance.

HEALTH & BEAUTY	AVERAGE WATTAGE	EST. KWH CONSUMED MONTHLY
GERMICIDAL LAMP	20	12
HAIR DRYER	1,000	15
HEAT LAMP (INFRARED)	250	1
SHAVER	15	.004
SUN LAMP	275	1
TOOTH BRUSH	1.1	.1
VIBRATOR	40	.2
HOME ENTERTAINMENT		
RADIO (SOLID STATE)	10	1
RADIO/RECORD PLAYER	109	9
TELEVISION		
BLACK & WHITE		
TUBE TYPE	100	18
SOLID STATE	45	8
COLOR		
TUBE TYPE	240	44
SOLID STATE	145	27
HOUSEWARES		
CLOCK	2	1.4
FLOOR POLISHER	305	1
SEWING MACHINE	75	1
VACUUM CLEANER	630	4

Table 5-5.

Using Minor Appliances: Some of these "gadgets" are necessary and helpful, but others are more convenient than efficient and waste a great deal of energy. Some small appliances could be eliminated by substituting simple human energy as a power source rather than electrical energy. This topic is controversial, and individuals will argue the merit of some small appliances over the alternate of manual labor. The point still exists, however, that the appliances cost money to operate. Is the user of the product willing or prepared to pay the price to operate them?

Figure 5-5 lists some small appliances which could be eliminated by substituting

ELIMINATING UNNECESSARY APPLIANCES

ELECTRIC APPLIANCES	KILOWATT HOURS CONSUMED ANNUALLY	SUBSTITUTE
BLENDER	15	EGG BEATER AND STRONG ARM
CARVING KNIFE	8	SHARP KNIFE
COFFEE MAKER	106	DO WITHOUT
DISHWASHER	363	WASH DISHES BY HAND
EGG COOKER	14	COOK EGGS IN BOILING WATER USED FOR TEA OR COFFEE
GARBAGE DISPOSAL	30	COMPOST FOOD WASTE
TRASH COMPACTOR	50	MANUALLY SHRED TRASH AND CRUSH CANS
CLOTHES DRYER	993	HANG CLOTHES TO DRY OUTSIDE IN SUMMER AND INSIDE IN WINTER (TO HELP HUMIDIFY)
IRON	144	WEAR PERMANENT-PRESS CLOTHING
ELECTRIC BLANKET	147	SLEEP WITH EXTRA BLANKETS
HUMIDIFIER	163	PUT A PAN OF WATER ON THE RADIATOR, HANG UP WET CLOTHES, OR OPEN THE BATHROOM DOOR AFTER A SHOWER
PORTABLE HEATER	176	HEAVIER CLOTHING
HAIR DRYER	14	DRY TOWEL, STRONG ARMS
GERMICIDAL LAMP	141	DO WITHOUT
SUN LAMP	16	GO OUTSIDE AND ENJOY THE SUNSHINE
SHAVER	1.8	GROW A BEARD
TOOTHBRUSH	.5	BRUSH BY HAND
VIBRATOR	2	PHYSICAL EXERCISE
CLOCK	17	WIND-UP CLOCK
CAN OPENER		MANUAL CAN OPENER
LAWN MOWER		HAND-POWERED MOWER
HEDGE CLIPPER		HAND-POWERED CLIPPER
SAW		HAND-POWERED SAW
PAINT MIXER		HAND-POWERED MIXER

SOURCE: CENTER FOR SCIENCE IN THE PUBLIC INTEREST

Figure 5-5

non-energy consuming means. The annual amount of KWH consumed by each appliance is also listed.

Some of these figures are not large. Others add up substantially. The use of such appliances adds to the 33% total world energy used by the 6% of the world's population which lives in the United States.

THE APPLIANCE LABELING PROGRAM

On December 22, 1975, the Energy Policy and Conservation Act enacted a law that established a labeling program designed to help consumers shop for energy-saving household appliances and equipment. The Federal Trade Commission and the Department of Energy are developing the procedures for appliance testing, labeling, and public information required by this law. These procedures and appliance labels began showing on the market in the fall of 1979.

The program is aimed at a variety of appliances that, together, account for roughly 90% of the energy used in the home. The appliances include clothes dryers, washing machines, refrigerators, freezers, ranges, television sets, humidifiers, water heaters, furnaces, dishwashers, and air-conditioners.

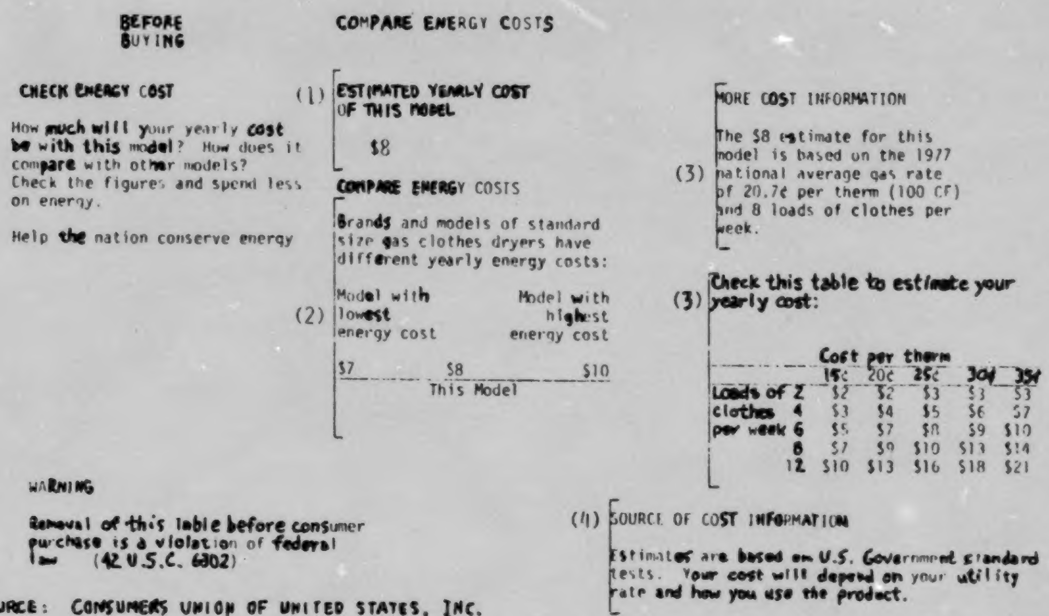
Eventually, the program will have a direct effect on the design of appliances, since the Department of Energy will set mandatory energy-efficiency standards. At first, however, the program affects only the way appliances are advertised and marketed, and require appliances to carry a label listing annual energy costs.

As proposed, the labels highlight the estimated annual operating cost for each appliance brand and model. The estimate is based on national average ranges of energy prices and on patterns of "typical" use. Finally, a chart shows how a specific model's energy cost compares with that of competing models. This is followed by a disclaimer noting that actual costs will vary.

A sample energy label is as Figure 5-6, on the following page. Some of the labels are small and reasonably straightforward, but others - notably those for humidifiers - are very elaborate.

The labels are intended to allow the customer to compare operating cost as well as price when shopping for an appliance. Government officials hope the labels

FEDERAL TRADE COMMISSION'S PROPOSED APPLIANCE LABEL



BEFORE BUYING

COMPARE ENERGY COSTS

CHECK ENERGY COST

How much will your yearly cost be with this model? How does it compare with other models? Check the figures and spend less on energy.

Help the nation conserve energy

(1) **ESTIMATED YEARLY COST OF THIS MODEL**

$8

COMPARE ENERGY COSTS

Brands and models of standard size gas clothes dryers have different yearly energy costs:

(2) Model with lowest energy cost — Model with highest energy cost

$7 — $8 — $10

This Model

MORE COST INFORMATION

(3) The $8 estimate for this model is based on the 1977 national average gas rate of 20.7¢ per therm (100 CF) and 8 loads of clothes per week.

(3) **Check this table to estimate your yearly cost:**

	Cost per therm				
	15¢	20¢	25¢	30¢	35¢
Loads of 2	$2	$2	$3	$3	$3
clothes 4	$3	$4	$5	$6	$7
per week 6	$5	$7	$8	$9	$10
8	$7	$9	$10	$13	$14
12	$10	$13	$16	$18	$21

(4) **SOURCE OF COST INFORMATION**

Estimates are based on U.S. Government standard tests. Your cost will depend on your utility rate and how you use the product.

WARNING

Removal of this lable before consumer purchase is a violation of federal law (42 U.S.C. 6302)

SOURCE: CONSUMERS UNION OF UNITED STATES, INC.

THE FTC'S PROPOSED APPLIANCE LABELS WOULD PROVIDE INFORMATION ABOUT ENERGY COSTS IN VARIOUS WAYS, AS SHOWN IN THIS HYPOTHETICAL LABEL.

1. THE ESTIMATED YEARLY COST FIGURE GIVES YOU ONE MORE FACTOR TO USE IN CHOOSING AN APPLIANCE. ALL OTHER THINGS BEING EQUAL, AN APPLIANCE THAT HAS A HIGH PRICE BUT A RELATIVELY LOW OPERATING COST MIGHT BE A BETTER BARGAIN THAN A LOW-PRICED MODEL WITH A HIGH OPERATING COST.

2. TO SHOW HOW A SPECIFIC MODEL STACKS UP AGAINST THE COMPETITION, THE LABEL WOULD COMPARE OPERATING COSTS FOR SIMILAR MODELS. IF THE RANGE IS FAIRLY NARROW (AS IT IS WITH GAS DRYERS, SHOWN HERE), YOU MIGHT NOT NEED TO USE THE LABEL INFORMATION.

3. BECAUSE FEW PEOPLE PAY NATIONAL AVERAGE ENERGY PRICES, AND BECAUSE PATTERNS OF USE VARY, THE LABELS WOULD GIVE A RANGE OF ESTIMATED COSTS FOR EACH MODEL.

4. AN IMPORTANT REMINDER: THE ESTIMATES ON THE LABELS MAY NOT REFLECT YOUR ACTUAL COSTS, BUT THEY MAY ALLOW YOU TO PICK OUT THE RELATIVELY EFFICIENT APPLIANCES. KEEP IN MIND, ALSO, THAT THE ENERGY-COST ESTIMATES ON THE LABEL INDICATE NOTHING ABOUT THE PERFORMANCE, CONVENIENCE, SAFETY, OR DURABILITY OF A PARTICULAR APPLIANCE.

Figure 5-6

will thereby add an extra element of competition to the marketplace, thus inducing manufacturers to design products that are more energy-efficient.

The appliance industry is far from pleased with the FTC's labeling regulations. Many manufacturers believe that the figures on the labels could mislead consumers because no two homes use an appliance in the same way, and because utility rates are changing. Therefore, it is impossible to set any meaningful estimate for the cost of operation. Others are concerned that the promotional exploitation of data based on the energy testing program may lead some people to believe that the appliances have been tested for performance, convenience, safety, durability, or some other factor not involved with energy. In addition, some critics claim the labels will not help much because the operating cost figures will vary only slightly from one appliance to another. Therefore, labels will be most useful when they show a fairly wide range of energy costs.

In addition to labels and advertising, the government is taking a direct approach to energy conservation by imposing mandatory minimum efficiency standards on the appliance industry. The standards, which should be put in final form within three years, will supplant a set of voluntary "improvement targets" mandated by the 1975 energy law.

Many industry representatives may have to stop making certain appliance models if the standards are too difficult or costly to meet. However, the disappearance of inefficient appliances should still leave plenty of room for consumer choice.

The upcoming government standards, along with the labeling program, are likely to mean higher list prices for appliances. Exactly how much higher is not certain at this point, but some early Department of Energy estimates show design changes called for under the voluntary target program will have added about $45 to the price of a refrigerator, for example, and about $60 to the price of a room air-conditioner. In theory, however, the customer could recover such price increases through lower annual operating costs, assuming the efficiency improvements do not shorten the useful life of the product, or increase the need to service it.

APPLIANCES AND ENERGY CONSERVATION

To summarize tips on how to save energy when buying or using appliances, here are a few general ideas to consider from the Department of Energy.

1. Don't leave appliances running when not in use. It's a total waste of energy. Remember to turn off a radio, TV, or record player when leaving a room.

2. Keep appliances in good working order, so they will last longer, work more efficiently, and use less energy.

3. When buying appliances, comparison-shop. Compare energy use information and operating costs of similar models by the same and different manufacturers. The retailer should be able to help find the wattage of the appliance. With that information, figure out how much it will cost to run the appliance chosen.

4. Before buying new appliances with special features, find out how much energy they use compared with other, perhaps less convenient, models. A frost-free refrigerator, for example, uses more energy than a manual-defrost model. It also costs more to purchase. The energy and dollars saved with a manual-defrost model may make up giving up the convenience.

5. Use appliances wisely; use the one that takes the least amount of energy for the job. For example: toasting bread in the oven uses three times more energy than toasting in a toaster.

6. Don't use energy-consuming special features on appliances if there is an alternative. For example, don't use the "instant-on" feature of a TV set. "Instant-on" sets, especially the tube types, use energy even when the screen is dark. Use the "vacation switch", if there is one, to eliminate this waste; plug the set into an outlet that is controlled by a wall switch; or have the TV servicer install an additional on-off switch on the set itself, or in the cord to the wall outlet.

Whether your appliances are new or old, you can learn to operate them in ways that will keep the operating costs down. The savings here can be just as important as with the newer and more efficient equipment. Another benefit is that appliances which are used efficiently last longer and give more trouble-free operation.

The first step is to use appliances only when you have to. Choose only the equipment that is really a help in getting work done, and then learn how to use it sparingly. The best way to learn how to do this is to keep a record of how much energy you are using. Look at the bills each month, and keep track of the number of kilowatt-hours of electricity or cubic feet of gas used. A good goal is to try to cut down the amount used by about a third.

ILLUMINATION

We live in a world in which we learn through and work with our eyes. Much of our learning is done indoors in the home and in the schoolroom. Most persons work indoors in factories, offices, and stores. Therefore, it is important that we study and work in rooms that are well lighted. In dim light or glaring or unsuitable lighting, our eyes tire easily and our muscles become tense. We may suffer from headaches, dizziness and indigestion. We are not so efficient as we would be with proper lighting.

Good lighting results from proper planning. We do not need the same amount of light to play checkers as to read the newspaper. A toolmaker and diemaker need much more light than a clerk in a store does. The color of our indoor lights also is important. Many department stores have lights in their dry-goods departments that duplicate the colors of sunlight. This is so that fabrics will look the same indoors as they do outdoors.

What we perceive as color is the result of visible radiation in certain wavelengths being reflected from a surface, while all the other wavelengths are transmitted or absorbed. Since most of the radiation arriving from the sun consists of visible radiation, or radiation concentrated near the visible spectrum, the criterion for reflectivity is closely related to color values. If an object obsorbs nearly all the visible radiation that strikes it, it appears black; if it reflects most of the radiation, it appears white, since white is the combination of all the colors in the visible spectrum. A red brick wall will reflect visible radiation in the red spectrum, while absorbing all other colors. Color perception within the visible spectrum is illustrated by Figure 5-7.

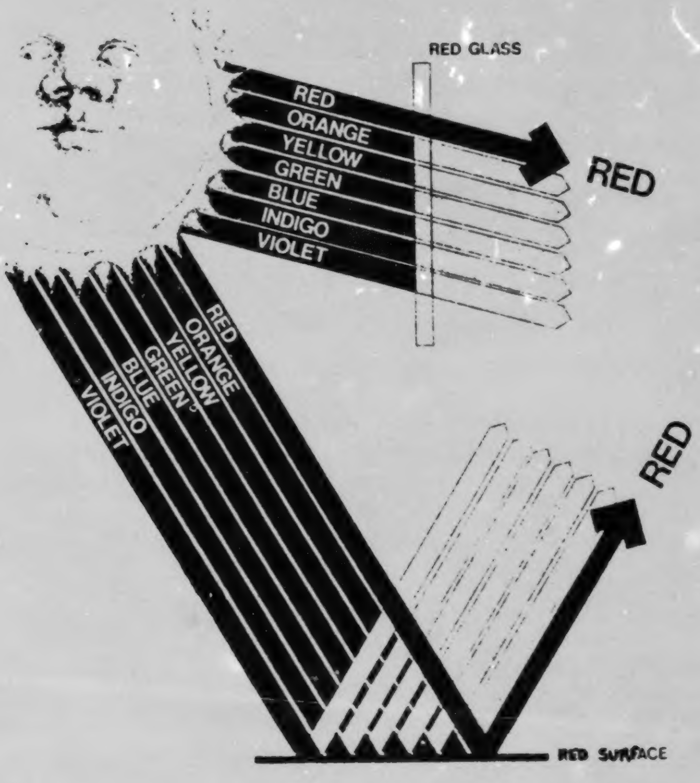

RED GLASS
RED
ORANGE
YELLOW
GREEN
BLUE
INDIGO
VIOLET
RED
RED
ORANGE
YELLOW
GREEN
BLUE
INDIGO
VIOLET
RED
RED SURFACE

Figure 5-7: Color Perception.

Most incandescent electric lights give off a yellowish light. This makes little difference in reading, for example, but it would if we were trying to match colors. The color of the light from fluorescent lamps is controlled by the use of fluorescent powers. Such lamps produce good imitations of natural daylight.

ARTIFICIAL LIGHTING

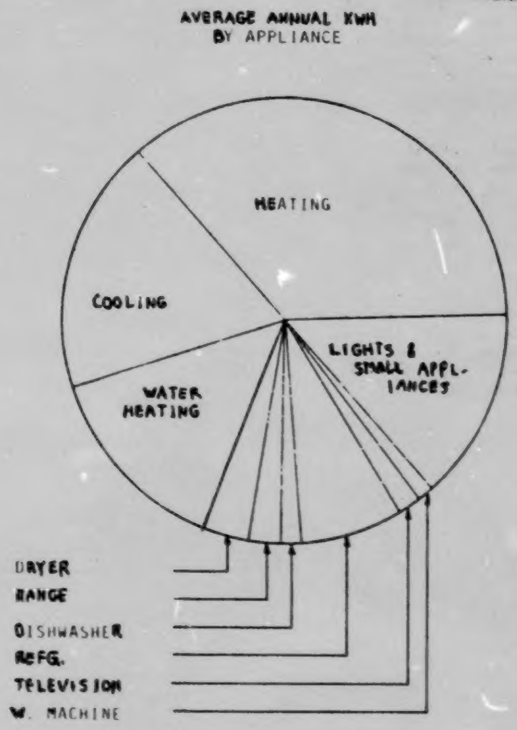
In itself, lighting is responsible for about 6% of our entire energy use. In addition, lighting supports a number of large industries - the manufacturers and suppliers of fixtures, and the suppliers of replacement tubes and bulbs, the suppliers and installers of wiring, conduits, and switchgear, and, of course, the public utilities. The corporations involved include some of the largest in the world - General Electric, Westinghouse, and General Telephone & Electronics. All told, the combined annual financial commitment to the lighting industry is about $20 billion.

According to General Electric, lighting accounts for an over-all average of 24% of all electric energy sold, and in some building types and in some utility companies' service areas, the percentage is much higher. As we have noted, commercial buildings on the average use over 60% of their electricity in lighting. The situation in schools is similar, somewhere in the neighborhood of 65%, although in most schools, electricity represents a smaller part of total energy use. Both of these figures do not include electricity used for heating or cooling, if these are done electrically. In New York City, with little heavy industry and a large share of its commercial space in high-rise office buildings, spokesmen for Con Edison said that about 40% of its sales were for lighting purposes. The lighting use and the electricity to provide it have grown explosively in the past two decades, primarily in response to a set of lighting recommendations published in 1959 by the Illuminating Engineering Society (IES), a quasi-professional group dominated by and financially dependent on the lighting industry. Since the amount of lighting affects the entire energy picture, we are primarily concerned with whether this increase is necessary, useful, and productive. If it is not, in what way has it been incorporated into the decision-making process and what has to be done to modify it?

Dependence on artificial lighting extends through our complete range of daily experiences, and the irrationality of light use permeates all of them. Each situation has its own set of rules and standards, but common components and the common source of energy to run the systems link them all together - our residential lighting arrangements, the well-publicized commercial lighting patterns, our methods of lighting our streets and roadways, the lighting within school buildings, lighting for advertising and merchandising, and even the lighting of our religious buildings. The lighting function in all cases is the same, to enable something to be seen effectively for some purpose. The means of perception is the same in all cases - the human eye.

Residential Lighting Demands

The total national energy cost in the United States in 1975 was $170 billion. This amount has more than tripled in recent years. Industry in our country uses 36% of this energy, commerce about 11%, and residences about 26%. Of the total household energy used annually, lighting accounts for 16% of that usage. (See Figure 5-8). That means the average home uses over 2000 kilowatt-hours of electrical energy each year simply for lighting. A local electric plant must burn about 150 gallons of oil or over 3/4 tons of coal to generate that amount of electricity.



SOURCE. TEXAS POWER & LIGHT COMPANY

Figure 5-8

Estimating Lighting Requirements

The unit of illumination is the footcandle, which originated as the amount of light falling on a surface placed one foot away from a lighted candle. In recent years this unit has been replaced by the candela, but most literature still uses the footcandle. A light bulb produces light energy that is measured in lumens. If one lumen of this light energy falls on one square foot of surface, the surface is said to have an illumination level of one footcandle.

Stores, factories, and office buildings typically have illumination levels of 100 footcandles or more and have drawn much criticism lately because that may be more light than necessary. Figure 5-9 lists the typical amount of light needed in various rooms for performing different tasks.

LOCATION OR TASK	FOOT-CANDLES
bathroom, general area	5
bathroom, at mirror	40
bedroom, general area	5
bedroom, at mirror	20
church, auditorium	10
classroom	30
closet	20
dining room	5
garage, storage area	10
garage, work area	50
hallway or corridor	5
ironing	100
kitchen, general area	10
kitchen, work area	40
living room, general area	20
office, service area	10
office, file work	30
office, close visual work	50
reading, short periods	20
reading, long periods	40
sewing, light fabrics	40
sewing, dark fabrics	120
stairway	10
utility room	10
writing	20

Figure 5-9

The number of light bulbs needed to achieve these general lighting levels varies with the type of fixture used and the coloring of the walls, floors, draperies, and furniture in the room. A formula to use for finding the number of light bulbs needed in an average room is:

$$\text{number of bulbs} = \frac{2 \times \text{foot-candles} \times \text{floor area}}{\text{lumens per bulb}}$$

For example, in a 12x15 foot living room, the floor area would be 180 square feet. Figure 5-9 shows the desired illumination level is 20 footcandles. If 100-watt incandescent bulbs are used, each bulb would emit 1,710 lumens.

The number of the bulbs required in this case would then be:

$$\frac{2 \times 20 \times 180}{1{,}710} = 4.2 \text{ bulbs}$$

Therefore, the need would be approximately four 100-watt bulbs. The lighting requirements depend upon the type of fixture, the placement of the lamps in the room, and room colors. If the bulbs were covered with a lamp shade, and the floors and furniture were medium to dark colors, two or three times as many bulbs may be needed to achieve a satisfactory lighting level. Light colors will increase the lighting level by reflecting and bouncing light around the room; dark colors will absorb light.

If one works near the lamp, the general level of light in the room will not be important. For example, one might be using a floor lamp or desk lamp for reading or sewing. The light level obtained directly from a bare light bulb is obtained from the formula:

$$\text{footcandles} = \frac{\text{lumens per bulb}}{12 \times \text{distance squared}}$$

For example, if one is reading a newspaper located 3 feet from a 100-watt bulb (1,710 lumens), the light level would be

$$\frac{1{,}710}{12 \times 3 \times 3} = 15.8 \text{ footcandles}$$

Normally, the lamp would have a shade that would help direct the light, so the amount of light falling on the newspaper would be increased to about 20 or 30 footcandles.

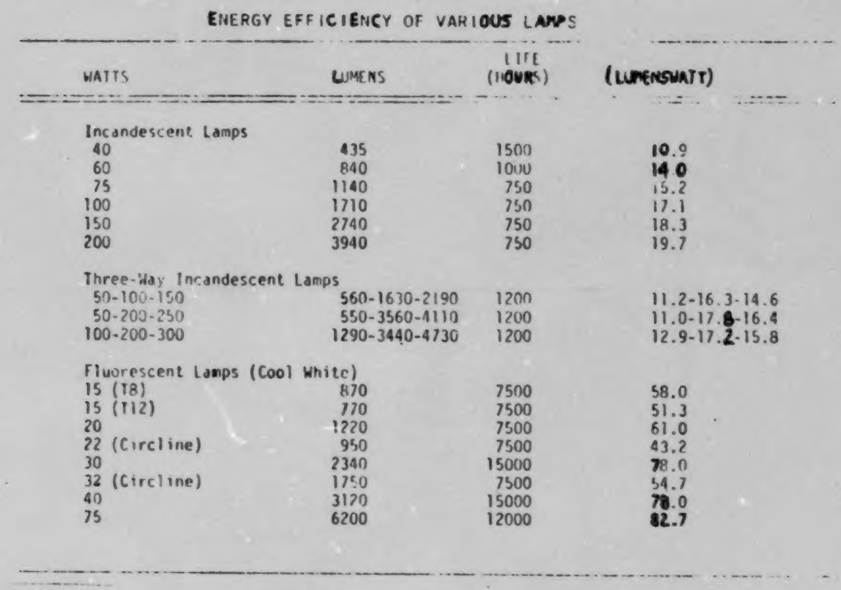
Note that the amount of light striking a surface decreases as the square of the distance; that is, the distance times itself. This means that, when one moves twice as far away from a source of light, only one-fourth as much light will be received. Similarly, if one is only half as far away, four times as much light would be received. To put this fact to work for you, consider a 30-inch high table standing below a flushmounted ceiling fixture in a room with an 8-foot ceiling. In this common situation, the light level on the table top will be about twice as much as at floor level without the table.

Lighting Efficiency

Light energy is important but the number of lights and the types of lighting fixtures used versus those required for certain activities greatly affect the electricity bill and the efficiency return for the energy spent. In other words, not all light bulbs and light fixtures are equal.

Some lights give off much more light energy than others, even though they consume the same amount of electricity. For instance, two 60-watt bulbs actually give off less light than a single 100-watt bulb. Or one 40-watt fluorescent bulb produces almost as much light as two 100-watt incandescents, while using less energy. Therefore, choice of lighting fixtures and bulbs can have a very significant effect on the electricity bill.

Figure 5-10 gives the light output of various lamps. The unit of light energy output is the lumen - the more lumens a lamp produces, the more light given. But the number of lumens is only one side of the story. Lamps are powered by electricity, so what is most important is the number of watts required to produce the desired amount of light. A measure of the efficiency



ENERGY EFFICIENCY OF VARIOUS LAMPS

WATTS	LUMENS	LIFE (HOURS)	(LUMENSWATT)
Incandescent Lamps			
40	435	1500	10.9
60	840	1000	14.0
75	1140	750	15.2
100	1710	750	17.1
150	2740	750	18.3
200	3940	750	19.7
Three-Way Incandescent Lamps			
50-100-150	560-1630-2190	1200	11.2-16.3-14.6
50-200-250	550-3560-4110	1200	11.0-17.8-16.4
100-200-300	1290-3440-4730	1200	12.9-17.2-15.8
Fluorescent Lamps (Cool White)			
15 (T8)	870	7500	58.0
15 (T12)	770	7500	51.3
20	1220	7500	61.0
22 (Circline)	950	7500	43.2
30	2340	15000	78.0
32 (Circline)	1750	7500	54.7
40	3120	15000	78.0
75	6200	12000	82.7

Figure 5-10: Energy Efficiency of Various Lamps

of a light source is the ratio of lumens to watts. Figure 5-10, on the previous page, shows that small incandescent lamps are less efficient sources of light than larger lamps. Note, however, that fluorescent lamps are much more efficient than incandescent lamps. In fact, a 40-watt fluorescent bulb gives off more than seven times as much light as a 40-watt incandescent.

Light Fixtures: The trend today in lighting fixtures is to use several low-wattage bulbs instead of one or two larger bulbs. Admittedly, this may make same lighting fixtures more attractive than others, but they do not use electricity as efficiently. For example, a ceiling fixture with four 40-watt bulbs, at an energy usage cost of 4¢ per kilowatt-hour, will use up to $18.69 of electricity per year, if it is used 8 hours a day. On the other hand, if 2 60-watt bulbs are used, the lighting fixture will give off the same amount of light, but will cost only $14.02 per year to operate - a savings of $4.67.

An additional savings comes about as you replace the bulbs that burn out during the year. If the fixture is on 8 hours a day, this amounts to just under 3000 hours a year. Presently, 40-watt bulbs have an average life of 1,500 hours, compared to the 60-watt bulbs, which last only 1,000 hours. But don't let this fool you! If you use 40-watt bulbs, you would have to replace all four bulbs twice each year, which would mean buying eight bulbs. If you used 60-watt bulbs, even though you would have to replace them three times during the year, you would still only have to buy a total of six bulbs, which would save you the price of two bulbs each year. Using one 100-watt bulb to replace four 40-watt bulbs would save you $7.01 plus the price of four bulbs per year. Your savings would be even greater if your requirement was to burn the lights longer each day, thus shortening their lives.

Factors Affecting Bulb Life: The life expectancy of any bulb is shortened a little each time it is turned on. In an incandescent bulb, the initial surge of current presents quite a shock to the filament inside. Note that most bulbs seem to burn out just as they are turned on. When manufacturers calculate the average life of a bulb, they estimate how often the bulb will be turned on during its lifetime. If the bulb were only turned on once, and left on, the bulb would probably burn several times as long. On the other hand, if the lights are turned on and off dozens of times each day, the life expectance of the bulbs will be shortened greatly, because electric light is produced by heating the filament in the bulb to a high degree in order for it to glow.

One controversy, which has been debated for some time, is whether one should turn off a light when leaving a room for only a short while. It is argued that the amount of electricity required during the surge when a bulb is turned on is greater than the electricity used to keep it on for a short period. The point, however, is not in the tiny amount of extra electricity that is consumed during the surge when the bulb is turned on, but in the extent to which the life expectance of the bulb is reduced.

If the cost to replace the bulb is weighed against the small amount of electricity consumed by being left on a few minutes, it will be noted the cost of turning on the bulb is roughly equal to the cost of electricity used in five minutes. In other words, if a bulb is turned off for less than five minutes, electricity will be saved, but in the long run, more money will be lost by having to replace the bulb sooner. This is one instance in which money can actually be saved by wasting a little energy.

The life of bulbs has received so much attention that manufacturers have developed "long-life bulbs". The claim is that these bulbs last several times longer than regular bulbs. It may be true that they last longer, but they do not give off as much light. The lumen output is printed on the package of each bulb. These bulbs last longer because the filaments do not get as hot, which means they do not give off as much light compared to regular bulbs.

Ironically, manufacturers charge a higher price for these long-life bulbs. Therefore, in the long run, the long-life bulb is a questionable bargain. If the bulb is needed in hard-to-reach places, such as stairwells and on high ceilings, it will be advantageous to install a long-life bulb for convenience of replacement.

Fluorescent Lights

Fluorescent bulbs last considerably longer than incandescent types. The life expectancy of these bulbs is usually calculated for industrial users who turn on the lights in the morning and leave them on until night. Fluorescent bulbs have filaments (called cathodes) at each end of the bulb to help the flow of current through the bulb. These filaments are heated slightly, but do not produce much light. Contrary to popular belief, most modern, rapid-start fluorescent tubes do not require surges of electricity when first turned on, and most tubes will not burn out faster as a result of frequent on-off-on cycles, which was a problem with older type fluorescent tubes.

Factories, offices, and stores use fluorescent lighting for one reason - to save money! Although fluorescent fixtures typically cost two or three times as much as comparable incandescent fixtures, the savings in electricity will normally pay for the difference in less than two years. From then on, fluorescent lighting costs far less than incandescent lighting. Figure 5-11 compares the advantages and disadvantages of using fluorescent lights versus incandescent bulbs.

CHOOSING A LIGHT

	Incandescent	Fluorescent
Energy Use	Less efficient, produces more heat than light: 95% heat, 5% light.	Over 4 times as efficient as incandescent and lasts 7-10 times longer: 30% light, 70% heat.
Cost	Initial costs are less than fluorescent lighting.	Operating costs are less.
Versatility	Light can be adjusted by interchanging different wattage bulbs. Gain flexibility by using three-way bulbs and multiple switch controls.	Usually are stationary, ceiling-type fixtures that provide diffused lighting.
Best Use	For specific, close-in lighting: study, sewing room, bedroom, living room, or any area that requires light for reading and writing.	For general lighting: large work areas, bathrooms, laundry room, basement, kitchen, hallways, stairways, recreation rooms, or any large room where diffused light is required.

Figure 5-11.

People expect fluorescent lights to be used in factories, hospitals, and industries, but they do not accept their use as readily throughout the home. There are two reasons suggested for this unacceptance:

1. Fluorescent bulbs give off a "cold" white light or blue haze unlike warm yellow or incandescent;

2. The box-like shapes of fluorescent fixtures do not have the "character" or versatility in design which incandescent fixtures can have.

The light produced by a fluorescent bulb is determined primarily by the mixture of phosphors used to coat the inside of the bulb. The most common phosphor mixture is called cool white (CW), and this is the type used in most factories, offices, and stores. Colored phosphors, such as red, blue, yellow, and green are used in many advertising signs. Other special phosphor mixes are used to make bulbs for growing plants indoors, which produce a light similar to true sunlight. There are alternatives to cool white if this makes one feel the home is like an office building.

Incandescent lamps give off a light that is somewhat yellowish in color. Putting a CW fluorescent bulb in the same room with an incandescent just accentuates this difference. Many people find the clash objectionable. They may tolerate CW bulbs in their kitchen or bathrooms, but they do not want them in their living rooms. However, there are warm white (WW) bulbs available from most electrical supply stores. These bulbs give off a yellowish light similar in color to incandescent light. WW bulbs are rarely found in department and discount stores. People seem to be unaware of their existence.

Manufacturers also make fluorescent lights using a *deluxe* phosphor mixture. Regular phosphors suffer from the fact that they do not produce a balanced spectrum of light energy. They produce light energy containing blues and greens, but lacking in reds and oranges. All colors in the light spectrum do not have to be present to make "white" light. A sampling of colors must be blended in the right proportions. Manufacturers have created *cool white deluxe* (CWX) and *warm white deluxe* (WWX) bulbs that balance the color spectrum by adding more reds and oranges. The CWX bulb still produces a light that "looks" just as white as a regular CW bulb, but if a bright red cloth is held under the two lights, a distinct difference can be noted. The red cloth will look drab and dull under the CW bulb, but it will be truly bright under the CWX bulb. The WWX bulb produces even more reds and oranges, giving the bulb a slightly pinkish appearance when placed next to a CW bulb. The "warm" light produced by the WWX bulb makes it attractive for use in the living areas of the home. Deluxe phosphors are even harder to find in stores.

Decorating with fluorescent fixtures is a harder problem to overcome because of their inherent "boxy" appearance. The most economical size fluorescent bulb to buy is the four-foot, 40-watt type, since this is the size used by the millions in offices and stores everywhere. Lighting fixtures using these bulbs are also quite inexpensive compared to other sizes. Most fixtures contain one, two or four bulbs; the most common being the two-light "rapidstart" fixture. Two-light fixtures are now coming in an increasing number of styles suitable for the living areas of the home. There are traditional white enamel fixtures for a kitchen, utility room, or other work area, or ones with trim that can be painted in any color desired. There are also prepainted fixtures with wood-grain trim. Office supply stores often carry a much lower selection of good-looking fluorescent fixtures than most department stores. Most fixtures have plastic covers to diffuse the light. Acrylic covers are more desirable than polystyrene, because they do not yellow or crack with age. Fluorescent fixtures cost more to manufacture and therefore cost more to buy than similar incandescent fixtures. Fluorescent fixtures use less electricity, however, and will pay for themselves in a short time. A 100-watt incandescent light bulb consumes 1 kilowatt-hour of energy every 10 hours. This is the same amount of energy needed to lift a 150-pound person 17,700 feet into the air. If this amount of energy can be cut down, think of the energy savings realized.

For a moderately large kitchen with a dining area, an incandescent fixture having four 75-watt bulbs would be needed to provide a good working light. Assuming that the lights are on for 8 hours each day and electricity costs 4 cents per kilowatt-hour, this incandescent fixture would cost $35.04 per year to operate, plus the cost of 16 bulbs, which would bring the total cost $43 per year. On the other hand, a twin-light rapidstart fixture containing two 40-watt fluorescent bulbs would require only about 95 watts to run. (The fixture's ballast transformer and lamp filaments would require about 15 watts).

The fixture would produce 37% more light, but would use only $11.10 of electricity during the year. The bulbs, costing only about $3 for both, would last for several years before they needed replacing, so their cost would average less than $1 per year. In this case, the cost difference amounts to about $31 per year and it would not cost much more than that to buy a good-quality fixture. Thus, after the first year, the fixture would have almost paid for itself, and from then on the savings would be $31 per year.

Lights and Heat Energy

Lights use electrical energy to make light, but most of the electrical energy goes into making heat. The light energy that is produced in the lamp strikes objects in the room and is eventually converted into heat energy. Thus, all of the electrical energy used in lighting fixtures results in heat energy. In the winter, this is desirable because it helps to heat the home. If electric heat is used, the cost is no more. Electricity is electricity; whether heat in the home is from electric baseboard heaters or light bulbs - the costs are the same either way. If using oil or gas heat which costs less than electric heat, one can at least realize that the lights are helping to heat the home, although somewhat more expensively. In summer, however, it costs money to remove heat energy with air cooling. In this case, the extra heat energy contributed by the lights is not desirable. For each watt of lighting power, about 3.4 Btu of heat energy must be removed. A 100-watt bulb thus creates 340 Btu of heat energy.

Each lamp used adds heat energy, increasing the electricity bill as it lights the house - and as it heats the house. In fact, all electric appliances produce heat energy that must be removed by the air conditioner.

Of course, people should not stumble around in the house with all the lights turned off. Lights are needed in order to see what one is doing. Lights are required when reading, working, playing, and even when watching television to cut down on the glare. The trick, though, is to use lights effectively, to avoid waste. This calls for a little planning and common sense. Position lamps where needed. Locate light switches conveniently. But most of all, provide the right amount of light for the type of work or recreation one is doing. Light levels that are too low will strain the eyes, and too much light simply wastes electricity.

WINDOWS TO PROVIDE NATURAL LIGHTING

Equally as important as the ability to see outside is the natural lighting which windows allow to enter a space. Because of wide fluctuations in outside illumination or light levels, interior illumination cannot be planned for with any large degree of certainty. Still, certain window shapes and locations give certain characteristic results.

Nearly all the useful light in a room comes from above. The light coming from low windows has first to be reflected off the floor, and then once again off the ceiling, to be much good for anything other than showing one where to step. For this reason, the reflectance levels of walls and ceilings are very important. A room maintains higher illumination levels when the walls are a light color and the ceiling is white. Openings for light placed well above the eye level bring us this daylighting directly and allow this light to penetrate to the very back of the room. Light entering a room near the floor, on the other hand, illuminates only that portion of the room adjacent to the window, and leaves the back part of the room quite dim. Running windows up past the standard 80-inch header height helps by allowing the penetration of light from above. Another aid to natural lighting in any room is venetian blinds. They reflect the incoming daylight up to the ceiling and shower the whole room with light; so does a long horizontal window placed high on a wall. It provides more light than the same window turned vertically, although the vertical window does offer a better view.

Both skylights and clerestories are windows designed exclusively for natural lighting from above. A clerestory is a horizontal, clear glass panel placed on a wall well above our line of vision to allow full daylighting of a space. A band of glass just a foot wide lets a great deal of light enter a room. The skylight is a window mounted in the roof of a building for the same purpose. Skylights are usually made of frosted plastic that diffuses the incoming light, although some are still of clear, unbreakable glass (wired or tempered). Skylights can be used where a roof doubles as a ceiling, while clerestories are dependent on a supportive architectural form. Thus, skylights are more adaptable than are clerestories. However, this flexibility is achieved only by skylights shedding water, and there are many leaky skylights on the market today. Check to make sure that the manufacturer of a skylight is reputable and that their product has proved durable. The right kind of skylight can be a good way of getting light from above. Also, with both skylights and clerestories, since they are placed in a warm area near the ceiling and also in an area hard to reach in terms of a curtain to retain heat on winter nights, it is imperative that you install equipment that will lose as little heat as possible. The only way to do this is to have the glass fixed in place and use three panes. The use of triple glazing will ensure that the heat lost at night is balanced by the light and heat gained during the day.

You should strive for a uniform illumination level from daylighting in any room, as large contrasts in light levels cause eye discomfort. Your eyes cannot adjust simultaneously to two contrasting light levels, and as a result they can feel strained. This "direct" type of glare is quite common where a traditional series of separate, small, "punched out" window openings creates intense bright areas on the otherwise dark wall they are placed in. The discomfort caused by this can be relieved by grouping these windows together, thereby eliminating the dark areas between them, as shown in Figure 5-12.

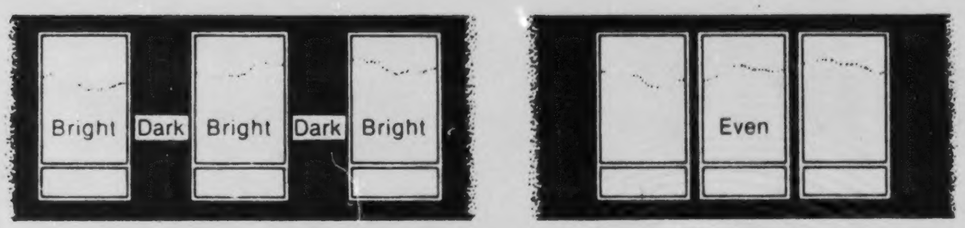


Figure 5-12: Grouping Windows Reduces Direct Glare

For the same reasons, corner windows or conventional bay windows do a poor job of increasing daylighting uniformly. However, by placing windows along two walls, you can help to even out the light in a room. If you are planning to have large south-facing windows in any room that is deeper than it is wide, you should plan on some additional lighting from the back, from above, or from the side to balance out the lighting in this room.

Glare is something to be avoided wherever possible. Direct glare can be avoided by a uniform lighting level. Reflected glare is caused by light mirroring off a work surface at the same angle it enters. See Figure 5-13, which appears on the following page. Fortunately, the work surfaces of a home are more flexible than a school chalkboard, where reflected glare is a common problem. If you're annoyed by reflected glare when working at the kitchen table, let's say, all you need to do is to shift your position to relieve the glare.

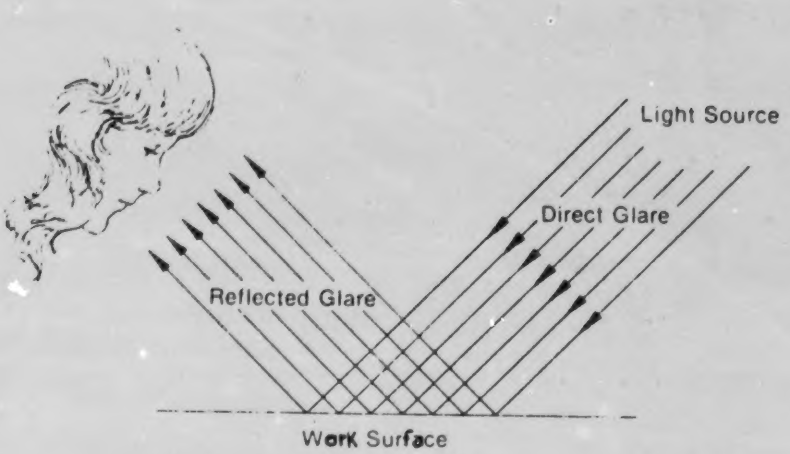


Figure 5-13: Direct and Reflected Glare

Many building codes require the glass areas in the walls of any room to be at least 10% of the floor area. Use caution when you apply any such rule-of-thumb to something as variable as natural lighting. This 10% is probably an adequate window area where most of the glass is at or above eye level. If your glass areas are near the floor, however, you should consider having a window area equal to 20% or more of the floor area. Since winter heat loss and summer heat gain are big problems with windows, try to keep your glass areas away from the floor. This way you can reduce fuel bills because of smaller windows and still have the light and view you need. An area of glass at eye level equal to 15% of the area of the floor is a good balanced design figure to work with. Then, a greater area can be used for south windows, and less area in north-facing windows.

To design your home to provide adequate daylighting will not just spare you the waste and expense of electricity. In the comfort of the natural colors which daylight provides, you will find less heat per unit of light to overheat your home in the summer than is produced by either fluorescent or incandescent lighting systems.

ILLUMINATION AND ENERGY CONSERVATION

The following Institute of Environmental Studies recommendations for the better utilization of energy expected for lighting is a generally accepted standard for lighting design and use. It will serve as a capsulization of tips on lighting the student will find helpful.

1. Design lighting for expected activity. More light is required for seeing tasks, with less light needed in surrounding, non-working area.

2. Design with effective lighting fixtures, and windows and skylights. Electric lighting and window lighting effectiveness depends on how well the light provided enhances the visibility of visual tasks. Light from either source, if not controlled, can reduce visibility by producing veiling reflections (reflections which will partially hide the details of a task and lower the task contrast) and disability glare (light scattered in the eyes producing a haze to look through - such as that experienced with oncoming headlights at night).

   It has been found, for example, that lighting from the side by electric lights of specific design can enhance task visibility by reducing veiling reflections. Conversely, a heavy concentration of light from overhead and forward of the task can produce a high degree of veiling reflections.

   Well-shielded (low brightness) luminaries can eliminate disability glare.

3. Use efficient light sources (higher lumen/watt output).

   a. For incandescent lamps, higher wattage lamps are more efficient. 40-watt general service produces about 11 lumens/watt input. 100-watt general service produces about 22 lumens/watt input. Therefore, in design, consider use of fewer and higher wattage lamps.

   b. For fluorescent lamps, longer length lamps are more efficient. Two 24-inch cool white lamps produce 50 lumens/watt.

Two 48-inch cool white lamps produce 67 lumens/watt.
Two 96-inch (800MA) cool white lamps produce 73 lumens/watt.

c. For HID lamps, (high pressures sodium and metal halide) higher wattage lamps are more efficient.
400-watt phosphor coated mercury produces about 46 lumens/watt.
1000-watt phosphor coated mercury produces about 49 lumens/watt.
400-watt metal halide produces about 74 lumens/watt.
1000-watt metal halide produces about 85 lumens/watt.
400-watt high pressure sodium produces about 100 lumens/watt.

d. For overall design, consideration should be given to the use of the more efficient sources such as fluorescent and HID.

4. Use more efficient bulbs. More efficient bulbs not only use energy more efficiently, but also can reduce the user's lighting costs. For example, incandescent indirect bulbs may require a load of 10 watts per square foot of floor area to produce a 50 footcandle level, but direct fluorescent lights may only require a load of about 2.5 watts per square foot.

5. Use heat transfer fixtures. By using bulbs with air or water heat transfer capabilities, heat from fixtures can be exhausted before entering an occupied space in warm weather, or conversely, the heat can be utilized in the occupied space in cold weather. By integrating the lighting and air conditioning systems, less room heating and cooling load should be required.

6. Use lighter finishes on ceilings, walls, floor and furnishings. Light finishes can increase the utilization of light. For example, by repainting ceiling, walls and floor and refinishing furniture, the average illumination level can be increased from less than 40 footcandles to over 100 footcandles.

In selecting light finishes, reflectances should be in the following range:

Ceiling Finishes	80-92 percent
Walls	40-60 percent
Furniture	26-44 percent

Office Machines & Equipment .... 26-44 percent

Floors .... 21-39 percent

The upper limits have been selected to avoid excessively bright surfaces, which can be uncomfortable or reduce visibility by producing disability glare.

7. Use efficient incandescent lamps. Higher wattage General Service lamps are more efficient than the lower wattage lamps. Therefore, using fewer higher wattage lamps may save power. For example, one 100-watt lamp produces more light than two 60-watt lamps (1740 lumens versus 2 x 860 = 1720 lumens).

   a. For the same wattage, General Service lamps (750 to 1000 hours life) are more efficient than Extended Service lamps (2500 hours life). For example, a 100-watt General Service lamp produces 17.4 lumens/watt input, while a 100-watt Extended Service lamp produces 14.8 lumens/watt input. For equal lighting results in this case, 17.5 percent more lamps and power are required when using Extended Service lamps.

   b. Extended Service lamps are used where maintenance labor costs are high or where lamps are in inaccessible locations.

8. Turn off lights when not needed. When a working or living space is empty, secure and not used for display or observation, there is no need for lighting. In this case it is always more economical to turn off incandescent lighting and, where off-time is more than a few minutes, fluorescent and high-intensity discharge lighting should be turned off.

   In areas where adequate daylighting is possible, photoelectric control systems can be utilized to turn off the electric lighting.

9. Control window brightness. The requirements for good lighting design can be achieved by skillful application of daylighting techniques. These techniques include:

   a. Redirecting available light for better interior distribution and utilization, such as with venetian blinds.

b. Limiting the brightness of fenestration to within comfortable (the same criteria as used for electric sources) by using devices such as: shades, screens, blinds, and low transmission glasses.

c. Controlling heat producing radiation entering a space by utilizing such means as reflective glass coatings and sun screening to reduce air-conditioning requirements.

10. Utilize daylighting as practicable.

11. Keep lighting equipment clean and in good working condition. Studies have shown that good lighting maintenance procedures provide better utilization of the lighting system.

    If better maintenance procedures are followed, it may be possible to reduce the wattage of incandescent lamps in a given system as long as adequate illumination is still maintained.

    In designing new lighting systems, more attention should be given to maintenance procedures and the consumer (tenant or owner) should be aware of the maintenance procedures considered in the design.

12. Be cognizant of planned operation and maintenance procedures. For building owners' and tenants' information, as consumers, all illuminated spaces should have a set of instructions covering the operation and maintenance of the lighting (electric or daylight), both for maximum utilization of power and for economic considerations.

REMEMBER - ONE-THIRD

Every home can save a substantial part of the money spent on appliance and lighting energy. It is a matter of selecting efficient equipment and learning how to use it properly. A reasonable goal for both new and existing homes is a one-third reduction in the amount of energy used and what the owner has to pay for the operation of this equipment. See Figure 5-14. The resultant yearly savings for the typical four-person home mentioned at the beginning of this module is about 2,500 KWH per year, worth $100 at 4¢ per KWH.

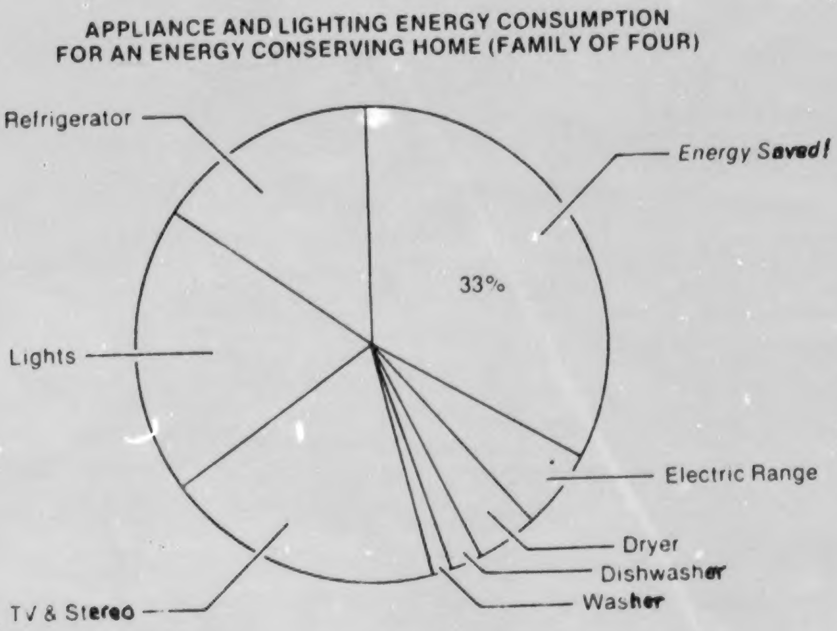


Figure 5-14.

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ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

PASSIVE SOLAR DESIGN CONSIDERATIONS

STUDENT MATERIAL

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

PASSIVE SOLAR DESIGN CONSIDERATIONS

INTRODUCTION

The earth experiences wide fluctuations in temperature at particular locations, but its large heat storage capacity (and the atmospheric envelope) prevents it from cooling off too much at night and from getting too hot during the day. Because of its large heat storage capacity, the earth takes a long time to cool off after the sun goes down and a long time to warm up after the sun rises. This accounts for afternoon temperatures being higher than morning temperatures, in spite of what are usually similar amounts of solar radiation at both times. The same principle accounts for the time lag between the earth's and the sun's seasons. Midsummer for the sun is the summer solstice, around June 21 in northern latitudes, but the warmest weather usually occurs in July and August.

Building design should be based on similar principles. It should not "notice" extreme weather variations from one hour to the next, nor from cold night hours to warm daytime hours. If possible, it should not even "notice" the wider extremes of summer and winter.

There are countless examples of indigenous architecture based on these criteria. The example with which we are most familiar is the heavy adobe home of the Pueblo Indians in the southwestern United States. During the day, the thick walls of hardened clay store the heat of the sun, preventing it from reaching the interior of the home. At night, the stored heat warms the interior of the space while the temperatures of the desert night plummet. The coolness of the night air is then stored in the walls, keeping the home cool during the day. Buildings which are made of heavy material such as stone and concrete will perform in a similar way in many climates.

In addition to eliminating the effects of daily extremes, a design should allow a building to modulate itself in such a way that it does not notice the extremes of the seasons. Caves, for example, have fairly constant temperatures and humidities all year round. Buildings which are covered with earth or have earth piled against the outside walls and those which are molded into the side of a hill will be less influenced by seasonal temperature variations.

A building should be designed to respond to the outdoors in another way. On sunny winter days, the building should be able to open up, in a sense, to let the sun shine in, and then to button itself up tightly, like a cocoon, to keep that heat from escaping. During summer days, it should close itself up to keep out the heat, but at night, it should open itself up to receive the cool night air.

If a building is designed properly, it will function as a solar collector, collecting heat when the sun is shining and storing it for later use. It ceases to operate when there is enough heat in storage and when the sun is not shining. During the summer, for instance, the collector will not operate if the building does not need heat. But it might be able to operate in reverse, circulating the heat storage medium through the building as if it were opening itself up to the night.

The importance of designing a building to complement and to interact with the climate and the powerful influence which this can have on the success of a building as a life-support system cannot be over-emphasized. It is extremely important that a discussion of the utilization of solar energy begin with an appreciation of this premise. This forces us to deal first with the fundamental methods of interfacing with the sun's energy directly, without the use of complicated and highly technical machinery and technology. Among solar energy enthusiasts and scientists, these methods (and materials) are described as low impact technology and passive. This means that there are few moving parts and that controls or machines of high technological origin are probably not used. If they are used, they complement other components in a sophisticated but simple system. Designers of these systems recognize that the human element of control is often more reliable than control by machines; if not, it is at least more flexible in its ability to provide for human need. In addition, these designers carefully weigh the energy and resource consumption in the manufacture and use of these systems and materials against their environmental benefits.

The best way of using the sun for heating, then, is to design and use a building as a natural solar collector, trying to avoid a reliance on high technology. A building must satisfy three basic requirements to achieve this:

1. The building must be a solar collector. It must let the sun in when it needs heat, and it must keep it out when it doesn't. It must also let coolness in when it needs it. This is done primarily by orienting and designing the building to let the sun penetrate through the walls and windows during the winter and by keeping it out during the summer with shading devices such as trees, awnings, venetian blinds, and a myriad of other methods.
2. The building must be a solar storehouse. It must store the heat for cool (and cold) times when the sun is not shining, and the cool for warm (and hot) periods when the sun is shining. Buildings which are built of heavy materials such as stone and concrete do this most effectively.
3. The building must be a good heat trap. It must make good use of the heat (or cool) and let it escape only very slowly. This is done primarily by reducing the heat loss of the building through the use of insulation, reduction of air infiltration, and storm windows.

Different climates have produced traditional architectural styles that are tailored to local conditions: compact massiveness for hot, arid regions with cold harsh winters, and double roofs in desert areas that have dependable sunshine plus wind for convective cooling. In fact, a house that is tuned to the local climate may not have the same construction on all four sides; wall thicknesses may be different, the fraction of window area may vary, and the windward side may be designed either to catch or deflect the wind.

The passive solar approach has major advantages including simplicity, low cost, reliability, and durability. It can be accomplished today by designing to let the sun penetrate directly through windows, walls, and roofs, and by including enough shading, insulation, and heat storage to maximize heat gain in the winter and minimize it in the summer.

The design of such buildings begins with an appreciation of building heat gains (due to direct sun, high outdoor temperatures, and energy sources inside the building) and heat losses (due to low outdoor temperatures and wind), and proceeds by focusing attention on heat storage and control of solar radiation. Application of natural space conditioning involves the orientation, shape, color, and materials of the building; the placement and size of windows, and the type and location of external shading.

There are two basic elements in every passive solar-heating system: south-facing glass (or transparent plastic) for solar collection, and thermal mass for heat absorption, storage, and distribution. Popular belief has it that a massive building must incorporate large quantities of these two elements. Studies show, however, that while there must be some thermal mass and glazing in each space, when properly designed, they are not necessarily excessive.

To establish a framework for understanding passive systems, the individual components that are significant to all system designs will be considered in the discussions that follow, leaving the assembly of appropriate components into the passive systems for the next module.

BUILDING SITE, SHAPE, ORIENTATION

The amount of care taken in placing a building on a site with respect to open space and sun is perhaps the single most important decision that can be made about a building.

Buildings blocked from exposure to the low winter sun between the hours of 9:00 a.m. and 3:00 p.m. cannot make direct use of the sun's energy for heating. During the winter months, approximately 90% of the sun's energy output occurs between the hours of 9:00 a.m. and 3:00 p.m. "sun time". Any surrounding elements, such as buildings or tall trees, that block the sun during these times will severely limit the use of solar energy as a heating source.

To take advantage of the sun in climates where heating is needed during the winter, find the areas on the site that receive the most sun during the hours of maximum solar radiation. Placing the building in the northern portion of this sunny area will:

1. Insure that the outdoor areas and gardens placed to the south will have adequate winter sun;
2. Help minimize the possibility of shading the building in the future by off-site developments.

Figure 6-1 illustrates the sun-site location and the influence of various potential obstructions.

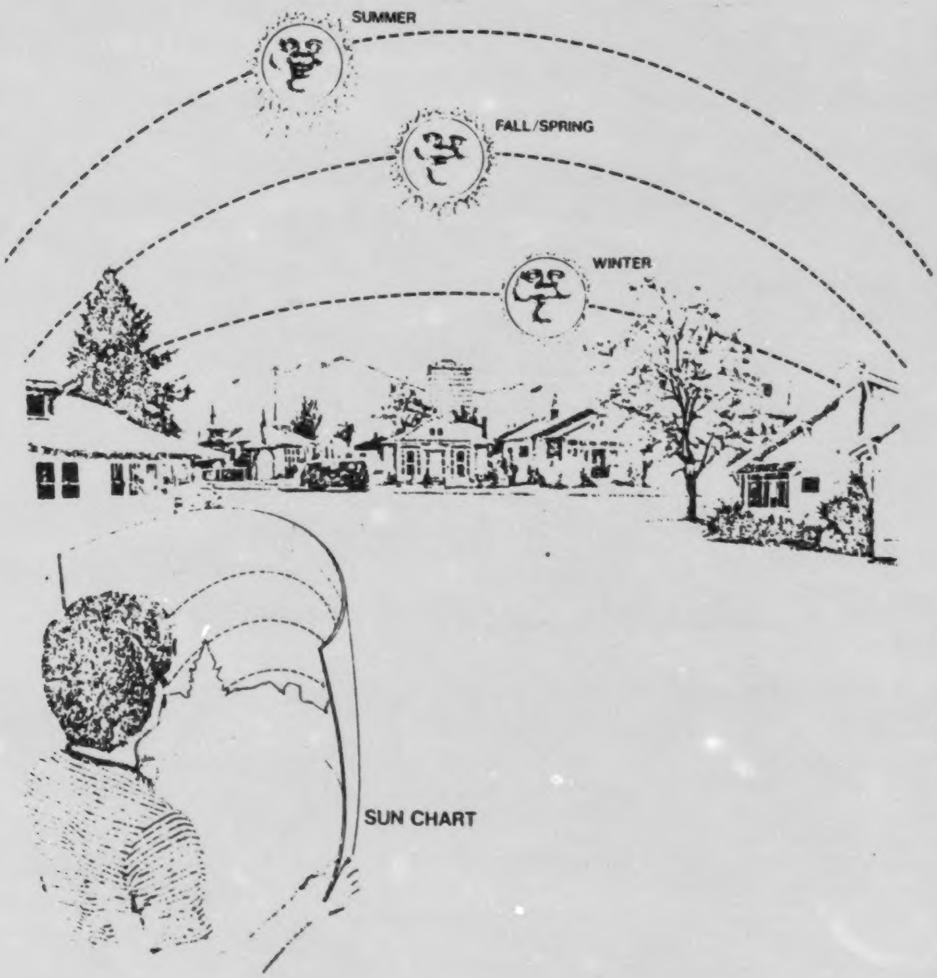

Figure 6-1: Using the sun chart to visualize solar obstructions

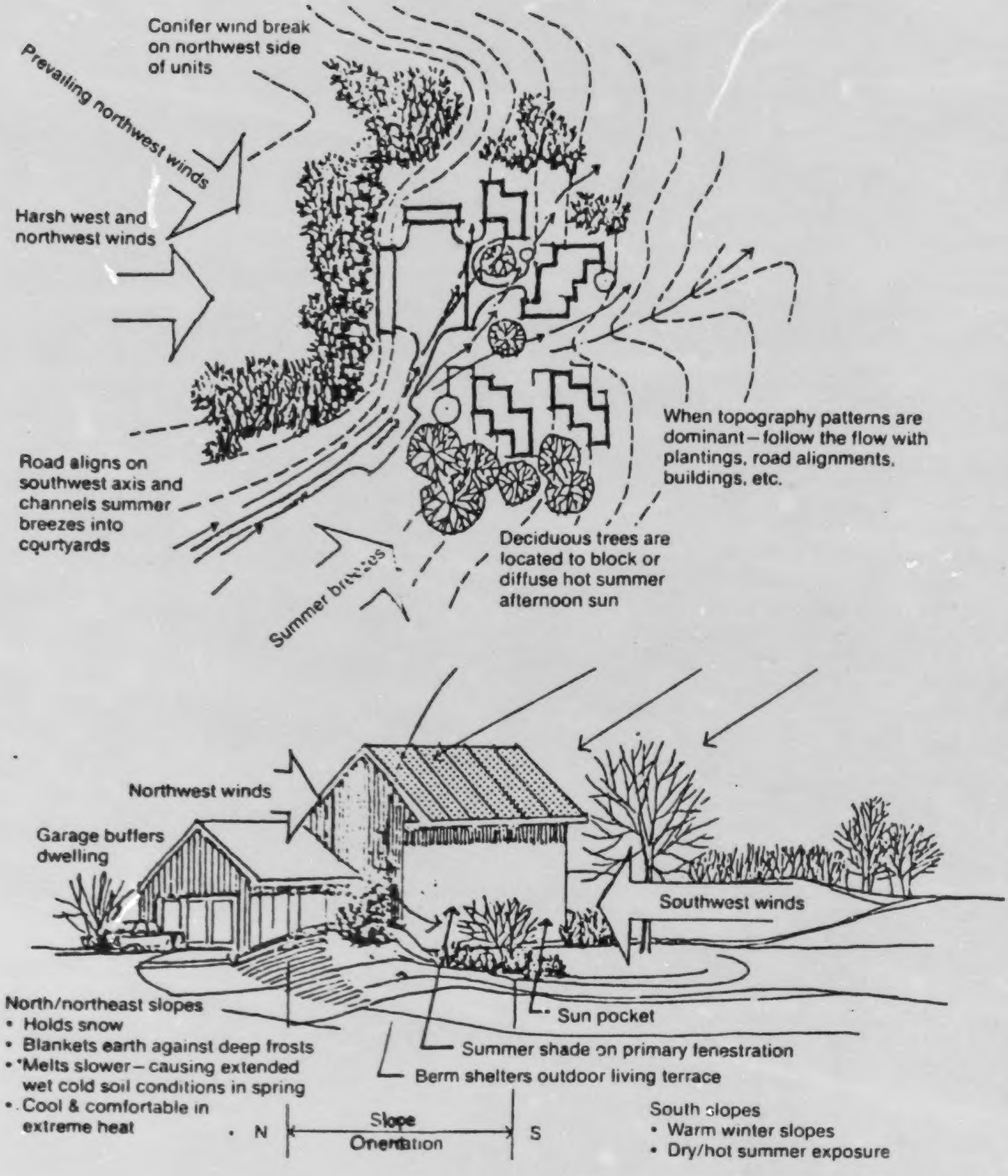
Conifer wind break on northwest side of units
Prevailing northwest winds
Harsh west and northwest winds
Road aligns on southwest axis and channels summer breezes into courtyards
Summer breezes
Deciduous trees are located to block or diffuse hot summer afternoon sun
When topography patterns are dominant – follow the flow with plantings, road alignments, buildings, etc.
Northwest winds
Garage buffers dwelling
Southwest winds
North/northeast slopes
• Holds snow
• Blankets earth against deep frosts
• Melts slower – causing extended wet cold soil conditions in spring
• Cool & comfortable in extreme heat
Sun pocket
Summer shade on primary fenestration
Berm shelters outdoor living terrace
N
Slope Orientation
S
South slopes
• Warm winter slopes
• Dry/hot summer exposure

Figure 6-2: A Sample Site Plan Illustrating Techniques for Minimizing Heating and Cooling Requirements

Siting

A wise decision about building placement should take into account local topography, sun angles, trees and other vegetation, ground water, precipitation patterns, and other aspects of the local climate and geography. There cannot be a simple, all-inclusive formula for resolving these issues, because each decision must be made on the basis of specific site conditions. Figure 6-2 gives an example of an efficient siting plan developed by the American Institute of Architects Research Corporation. The following figures were used in developing the plan:

1. The use of windbreak planting;
2. The orientation of road alignment with planting on either side to channel summer breezes;
3. The location of units in a configuration suggested by topography;
4. The use of the garage to buffer the dwelling from northwest winter winds;
5. The use of berms to shelter outdoor living terraces;
6. The use and location of deciduous trees to block or filter afternoon sunlight in the summer.

In warmer climates, a building should be placed at the highest part of the terrain to take advantage of cooling winds (a form of solar energy); in cooler climates, it should be located, ideally, in the cup of a hill, allowing sunlight to reach the building, while protecting it from chilling winds.

When the terrain and local building codes permit, siting at least part of the building underground or at ground level provides excellent insulation. Trees are also an important factor in site selection, acting both as a windbreaker and a lightbreaker. Deciduous trees shade the south side of the house for much of the year, allowing sunlight to penetrate during the cooler months. The same shading principle is true of such plants as ivy on the walls of the house.

Figure 6-3 indicates some of the basic elements of building siting decisions for four different climatic regions.

Type of climate	Cool	Temperate	Hot humid	Hot arid
Adaptations	Maximize warming effects of solar radiation. Reduce impact of winter wind. Avoid local climatic cold pockets	Maximize warming effects of Sun in winter. Maximize shade in summer. Reduce impact of winter wind but allow air circulation in summer	Maximize shade Maximize wind	Maximize shade late morning and all afternoon. Maximize humidity. Maximize air movement in summer
Position on slope	Low for wind shelter	Middle-upper for solar radiation exposure	High for wind	Low for cool air flow
Orientation on slope	South to southeast	South to southeast	South	East-southeast for p.m. shade
Relation to water	Near large body of water	Close to water, but avoid coastal fog	Near any water	On lee side of water
Preferred winds	Sheltered from north and west	Avoid continental cold winds	Sheltered from north	Exposed to prevailing winds
Clustering	Around Sun pockets	Around a common, sunny terrace	Open to wind	Along E-W axis, for shade and wind
Building orientation*	Southeast	South to southeast	South, toward prevailing wind	South
Tree forms	Deciduous trees near building; evergreens for windbreaks	Deciduous trees nearby on west; no evergreens near on south	High canopy trees; use deciduous trees near building	Trees overhanging roof if possible
Road orientation	Crosswise to winter wind	Crosswise to winter wind	Broad channel; E-W axis	Narrow; E-W axis
Materials coloration	Medium to dark	Medium	Light, especially for roof	Light on exposed surfaces, dark to avoid reflection

Figure 6-3: Site Orientation Chart.

Key energy-related objectives in site planning relate to orientation for solar gain (to capture heat when needed) and orientation for breezes (to provide natural ventilation when needed). It's not always possible to maximize both objectives - orientation for solar gain and orientation for natural ventilation - at the same time. When a compromise is required, begin to establish which of the two objectives has the higher priority for the project.

Orientation for Solar Gain: For passive solar collection, south-facing glass should total 1/4 to 1/5 of the floor area (temperate climates) or 1/3 to 1/4 of the floor area (colder climates). These are general rules, which, in temperate climates, and with appropriate insulated shutter and heat storage mass, can provide between 40% and 90% of the heating required.

Use an isogonic chart to locate south. (Remember, a compass indicates magnetic, not true, north). Additional data on solar altitudes and bearing for your area, and for critical times of the year, are available from the Weather Bureau or Solar Atlases.

Be sure that trees, hills and/or buildings do not cast shadows on your south-facing glass during the winter. (Also insure that your building does not infringe on the 'solar rights' of others).

Design overhangs to provide full shading of glass areas in the summer and during the most intense solar insolation periods. Deciduous trees on the south side will also help - providing shading in the summer and permitting solar penetration in the winter.

In orienting the building, remember that each facade has its own climatic conditions and thus its own energy-conscious design characteristics. As an example, vertical shutters may be appropriate on one facade, horizontal on another, and sliding on a third.

Orientation for Natural Ventilation: Locate the facade through which breezes will enter at an angle of 20° to 70° between wall and wind direction (Figure 6-4). This increases turbulence and provides better ventilation.

When wind velocity is low, it is beneficial to maximize the velocity of the ventilating currents. This can be done by using wing-walls extending from the exterior wall to create mini-pressure zones in front of the window openings. The depth of the projection should be no more than one-half of the distance between windows on the same facade. Casement windows, or operable shutters, extended perpendicularly to the wall can serve the same function.

Window sills should be located at the height where ventilation is desired. In bedrooms, for example, sills should be located at the same elevation as the mattresses inside.

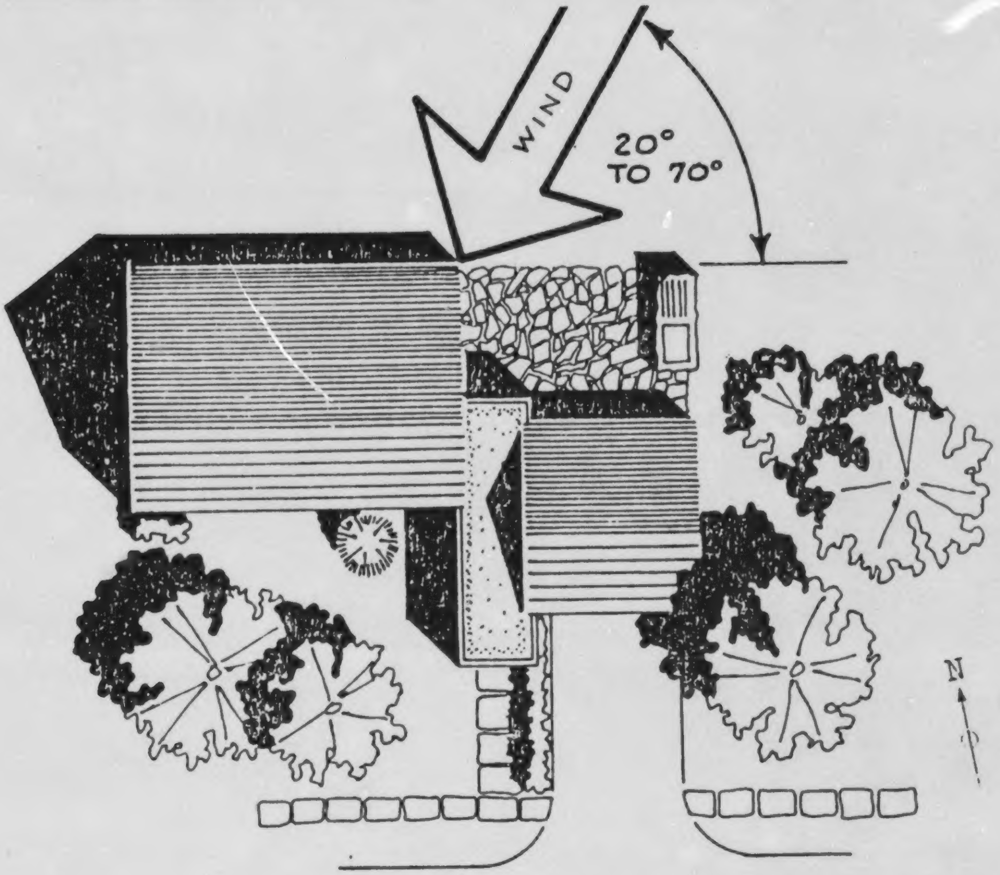

Figure 6-4: Orientation for Natural Ventilation

Locate evergreens on the north and west sides to block arctic winds.

When sites slope, particularly to the south, breezes move up the hill by day and down at night. Near bodies of water, breezes move from water to land by day and from land to water at night, as shown in Figure 6-5, on the following page.

Building Shape and Orientation

With an idea for the location of the building on the site, it is then important to define the rough shape of the building, with consideration for admitting sunlight into the building, before laying out interior spaces.

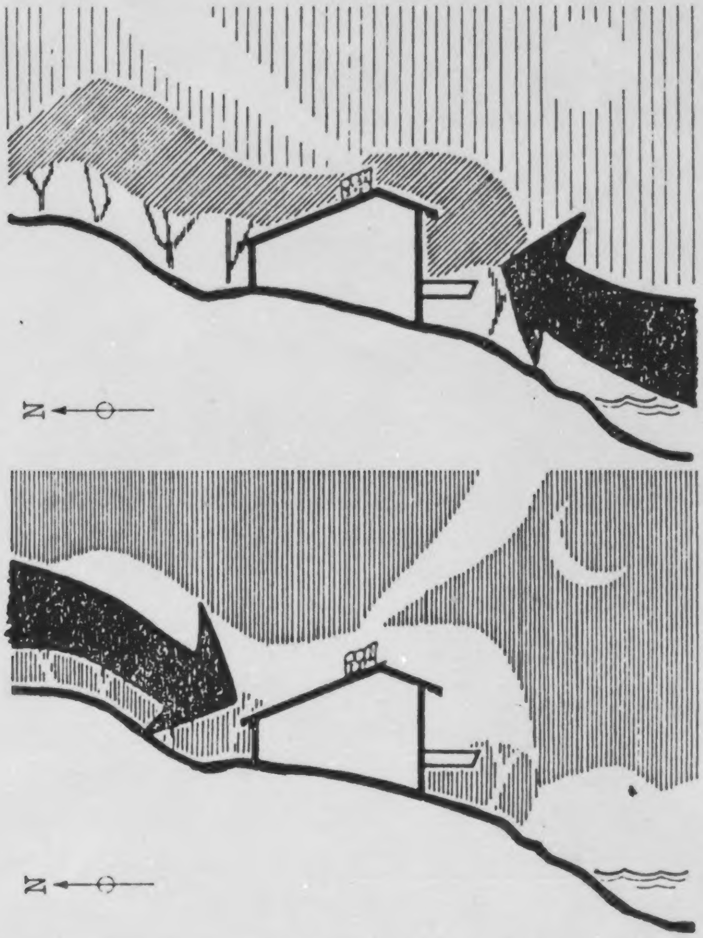

Figure 6-5: Influence of Topography and Water Bodies on Natural Ventilation.

Buildings shaped without regard for the sun's impact require large amounts of energy to heat and cool. The optimum shape of a building is one which loses a minimum amount of heat in the winter and gains a minimum amount of heat in the summer.

When deciding on the rough shape of a building, it is necessary to think about admitting sunlight into the building. A building elongated along the east-west axis will expose more surface area to the south during the winter for the collection of solar radiation. This is also the most efficient shape, in all climates, for minimizing heating requirements in the winter and cooling in the summer. At all latitudes, although buildings elongated along the east-west axis are the most efficient, the amount of elongation depends upon the climate. Some general principles can be stated for different climates:

1. In cool and hot-dry climates, a compact building form exposing a minimum of surface area to a harsh environment is desirable;
2. In temperate climates, there is more freedom of building shape without severe penalty (excessive heat gain or loss);
3. In hot-humid climates, building should be freely elongated in the east-west direction. In this climate, because of intense solar radiation on the east and west sides, buildings shaped along the north-south axis pay a severe penalty in energy consumption (for cooling);
4. In all climates, attached units (such as row houses) with east and west common walls are most efficient, since only the end units are exposed on the east and west faces.

Assuming that a building elongated along the east-west axis is compatible with other site and design considerations, to give the building a rough form, the building width must be determined. When the primary source of sunlight entering a space is through south-facing windows, then the depth of spaces along the south wall of the building should not exceed 2-1/2 times the height of the windows from the floor. This assures that sunlight will penetrate the entire space. This rule of thumb also provides for adequate daylighting of interior spaces.

The outside color and texture of a building also have some effect on the inside temperature. Dark colors absorb more of the incident sunlight than light colors do, and rough-textured surfaces absorb more than smooth surfaces, particularly if the sunlight is striking at an oblique angle, in which case smooth surfaces tend to reflect. However, as more insulation is added to the skin of the building, the effect of exterior color and texture decreases, since less of the absorbed heat gets through to the inside.

The North Side: Even though a building is located in the northern portion of a sunny site, the adjoining outdoor spaces to the north need sunlight to make them alive. When giving the building a rough shape it is necessary to consider the building's impact on the outdoor spaces to the north.

The north side of a building is the coldest, darkest, and usually the least used side because it receives no direct sunlight all winter. From September 20 to March 20 (6 months) the north wall of a building and its adjoining outdoor spaces are in continual shade. During these months the sun is low in the southern sky, rising along the horizon in the southeast and setting in the southwest. Any ice, snow or water on the north side of the building will remain there for long periods of time, making the area unusable. With the prevailing winter winds from the north and/or west in the United States, the north side of a building is even less desirable as an outdoor place.

The building should be shaped so that its north side slopes toward the ground. When possible, build into the side of a south-facing slope and/or berm earth against the north face of a building to minimize the amount of exposed north wall. As the height of the north wall is reduced, the shadow cast by the building in winter is shortened. A light-colored wall (or nearby structure) to the north of the building can be used to reflect sunlight into north-facing rooms and outside spaces.

Locate spaces in the building that have small lighting and heating requirements to the north. These spaces act as a buffer between the living spaces and the cold north face of the building.

HEAT GAIN

After giving the building a rough shape, the interior spaces need to be placed within this shape according to their requirements for sunlight. A space that does not directly utilize sunlight for heating during the winter months will use proportionally more conventional energy than one that does. Approximately 58% of the energy consumed by the average American household each year is for space heating. The more direct sunlight used to heat a space, the less conventional energy is required for space heating. This also applies to active solar-heating systems. If the design of a space does not directly take advantage of the winter sun to supply some of its heating requirements, an active solar-heating system will be proportionally that much larger and more expensive.

Interior spaces can be supplied with much of their heating and lighting requirements by placing them along the south face of the building, thus capturing the sun's energy during different times of the day. Place rooms to the southeast, south, and southwest, according to their requirements for sunlight. Those spaces having minimal heating and lighting requirements such as corridors, closets, laundry rooms and garages, when placed along the north face of the building, will serve as a buffer between the heated spaces and the colder north face. Figure 6-6 illustrates the basic principles of indoor space location.

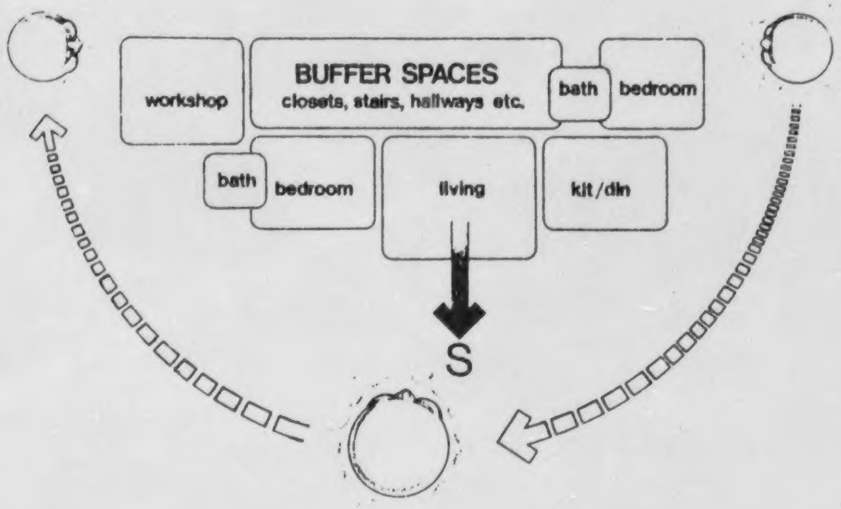

Figure 6-6

Locate openings to admit sunlight and provide for ventilation, while at the same time choosing the most appropriate heating system for each space. If a greenhouse is integrated into the building, place it along the south face of the building for maximum exposure to the winter sun.

Window Design

Passive solar architecture recognizes the importance of windows as an energy asset to a building. Windows can affect energy-using systems accounting for two-thirds of the energy consumed in buildings. Under these circumstances, the question of how to design windows to improve their energy performance is vital not only for passive solar designers but for all building designers.

The question of how to improve the performance of windows can best be addressed by first considering their six possible energy control functions. These are to provide: passive solar heating, daylighting, shading, insulation, air tightness and natural ventilation. One can then begin to evaluate numerous design strategies that affect but are not necessarily an integral part of the window. Strategies have been categorized into six sets: site design, exterior appendages, window frame, glazing, interior accessories, and building interior. In the interest of brevity, only one example from each of the six categories is presented.

Site Design: Site design strategies are advantageous because the thermal performance of doors, walls and roofs as well as windows, benefits from the favorably altered local solar, wind, or air temperature patterns.

One example of site strategy is the placement of a windbreak upwind of a building. Since in many areas of the U. S., the wind direction varies seasonally, a windbreak may be placed to afford protection from the winter wind while not inhibiting desirable summer breezes. Data for local wind direction and average velocity can be obtained from the National Climate Center, Federal Building, Asheville, NC 28801.

A planted windbreak should be located upwind a distance not further than one to one and a half times the building height. If a fence windbreak is desired rather than a planted windbreak, it should be closer to the house, and it should allow part of the wind to pass through. This evens out the turbulence, which would otherwise occur behind a solid fence.

A properly designed and located windbreak affords two important benefits: reduced infiltration heat loss, and reduced surface heat loss. Infiltration is reduced because the sheltering effect of a windbreak reduces the wind pressure on the joints and cracks of windows. Surface heat loss is reduced because a windbreak reduces the wind speed and consequently, the boundary layer of still air is preserved. It is the boundary or surface layer of air which provides most of a single-glazed window's thermal resistance.

Exterior Appendages: Like site strategies, exterior appendages have the distinct advantages of intercepting adverse climatic forces on the outside of the window. Consequently, residual forces such as heat from absorbed sunlight are dissipated to the outside air rather than to the room air where compensation is ultimately provided by the mechanical system.

One very effective exterior appendage is a roll blind. Roll blinds are common in Europe but have only recently appeared in the U. S. This device consists of horizontal wooden, aluminum, steel, or vinyl slate which are unrolled from a storage box at the window head, down the outside face of a window. The blind is operated by a rod or strap on the indoors side of the window. Thus, access to the outside is not necessary, an important advantage if storm sash or insect screens are present.

When lowered, a roll blind can provide several energy functions. For example, by pivoting the entire blind out awning fashion, natural ventilation is accommodated concurrently with shading. Furthermore, ground reflected light is admitted to provide daylighting. In the winter, the lowered blind effectively entraps a layer of air between itself and the window. The insulation value of the window and roll blind is comparable to double glazing. It is true that due to the desirability of sunlight during the day, the blind would only be lowered at night. Outside temperatures are coldest at night, however, so the blind provides insulation during the period of greatest need.

Frame: Window frame design is important for several reasons. The width of the frame determines how much glass area is possible for a given wall opening. The direction the window opens directs the incoming or exiting air stream. Finally, the tilt of a window affects the transmission of the glass. The latter phenomenon is the subject of the example frame strategy presented here.

By tilting a window toward the ground, the summer solar load is reduced while the winter solar gain is largely unaffected. How is this possible?

There are two causes. First, a window tilted in this manner has less area exposed to the overhead sun. This is accounted for in the cosine reduction formula. (The per-square-foot solar intensity measured on a plane normal to the sun is reduced by the cosine of the incident angle between the sun and a perpendicular to the plane of the window). Second, and commonly not considered, the solar transmissivity of glass decreases as the incident angle increases. This variation becomes substantial at angles exceeding 57° for common window glass. In the summer the sun's high path results in large incident angles to the window. Therefore, an increase in incident angle due to a window being tilted towards the ground results in a considerable decrease in the solar transmissivity of the glass. In the winter the sun's lower path results in incident angles less than 57° during much of the day. A change in incident angle due to window tilt is therefore inconsequential in the winter and beneficial in the summer.

To illustrate this phenomenon, consider a west-facing window in Philadelphia on July 21 at 4 p.m. If the window is vertical, the glass will transmit 78% of the incident solar radiation. If the window is tilted 45° towards the ground, only 35% of the solar radiation is transmitted. Thus, by merely tilting a sheet of clear glass it can become as reflective as many of the high performance glasses with reflective coatings or films. Furthermore, the strategy of tilting the glass can generate quite interesting architectural forms.

Glazing: Glazing strategies are effective to the extent that the glass is the last chance to stop adverse climatic forces outside the building envelope. Important performance requirements include the ability of the glazing to transmit valuable daylight, reject summer solar radiation, provide insulation against conducted winter heat loss, and finally, to admit winter solar radiation. This list is seemingly self-contradicting until one considers that the glass need not perform all the above functions, if the window is designed using the comprehensive approach being advocated here.

A frequently overlooked but very interesting glazing material is glass block. This material has several unusual properties, which can be exploited quite effectively for energy conservation.

The U value of glass block can be as low as 0.44 for a 12-inch square unit with a double cavity. Double cavity glass blocks obviously are better insulators than single cavity blocks, and larger face dimension blocks are better than smaller units. This is due to the higher rate of conducted heat flow through the joints (as opposed to through the cavities) and the lesser number of joints occurring per given area with large glass blocks.

As well as being fairly good insulators which transmit sunlight, glass blocks also have substantial mass. The part of the solar radiation which is absorbed in the glass is consequently not immediately radiated as with window glass. Rather, the glass block stores some of the heat. Design guides acknowledge this by recommending that the solar heat gain factor from the previous hour be used for any given hours. This thermal lag suggests opportunities to regulate the solar gain better to harmonize with the use schedule and spatial configurations of a building.

A second interesting property of glass block is the potential to regulate the transmitted light, both in the percent transmitted and the direction in which it is projected. Glass block can be specified from very clear units (78 to 84% visible light transmission, versus approximately 88% for clear glass) to opaque units. Units can also be specified with the insude surface of the block cast in various prism configurations. This option can be employed to direct daylight up to the ceiling to provide a more uniform light level and deeper penetration of light into a room.

Interior Accessories: Strategies occurring on the indoors side of a window offer one distinct advantage: accessibility. The example strategy selected from this category takes advantage of this feature by depending upon occupant management of the system as outdoor conditions or indoor requirements change. This system consists of a guide frame and three film shades: one heat absorbing, one reflective, and one clear; it is illustrated in Figure 6-7, which is shown on the following page.

During winter days, the heat-absorbing and clear shades are lowered. When the sun heats the air between the two shades to a higher temperature than the room air, bimetallic activated vents spring open the the warm air is convected into the room. When the temperature of the air space is cooler than room air, the vents close, preventing reverse cycling. At night, all three shades are lowered. The guide frame provides a relatively tight seal, so that the three air spaces between the shades provide excellent insulation. During summer days, the clear and reflective shades are lowered both to reflect solar gain and to insulate

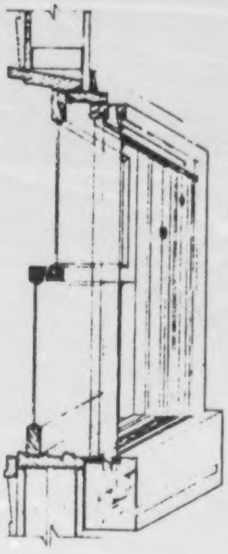

Figure 6-7: Ark-tic-seal Inc. Residential Window Application

against conducted heat gain. Finally, during summer evenings, all shades are raised, allowing unobstructed natural ventilation.

This system has two important advantages. First, collecting and distributing solar heat at the window (rather than at the room interior surfaces) alleviates the problems of fabric fading and glare from direct sunlight. Second, contrast glare is diminished (glare of a bright window contrasted against the darker surrounding wall) because of the reduced light transmission by the heat-absorbing or reflective shades.

Building Interior: After solar energy is admitted by a window, its usefulness depends largely on the design of the building interior. An obvious example is the coupling of thermal mass with extensive south-facing glass to reduce the frequency of daytime overheating and nighttime shivering.

One interesting application of this strategy is the Michael Jantzen vacation house in Illinois. Insulated steel water tanks are located beneath window seats in separate window alcoves. The ceiling of each alcove is a sloping skylight with a hinged exterior insulating lid. During winter days, the insulating lid is raised. An aluminized Mylar film on the underside of the lid adds reflected solar gain to the direct solar gain. The cushions are removed from the window seats exposing the top of the steel water tank to the solar radiation from both the skylight and the vertical window. At night, the skylight lid is lowered, reducing night sky radiation losses, and the water tank gives back its accumulated heat. Thus, we see an effective modification of the aesthetically pleasing concept of a window seat into a passive solar collection and storage system.

Summary: In designing a passive solar system, it is important to consider not only the solar heating potential of windows. Rather, one should consider all six of the possible energy control functions of windows, which also include daylighting, insulation, air tightness, ventilation, and shading. Enhancement of these possible window functions is not limited to the selection of glass, but can also include strategies involving the site, exterior appendages, the window frame, interior accessories, and the building interior. By considering a combination of window strategies selected from these six categories to enhance the six energy control functions of windows, buildings can be made less dependent on energy-consuming mechanical and illumination systems to accommodate environmental needs.

Window Orientation

Most glazing is highly transmissive for sun rays which strike the surface within a 60° angle to the perpendicular. Beyond this angle, the transmission falls off markedly, and most of the energy is reflected from the glazing surface, depending on the type of glazing. This effect enhances the winter-summer selective characteristic of south-facing, vertical glazing. In the summer the solar incidence angle is very large, and thus must of the energy is reflected, whereas in the winter, the angle is relatively small and most of the energy will be transmitted. These considerations lead to curves such as shown in Figure 6-8 on the following page, for the total amount of clear-day solar energy penetrating various double-glazed surfaces of a building.

Note that the solar energy transmitted through south-facing, double glazing is generally in phase with the thermal loss of the window, and far greater in magnitude. The loss curve is drawn for Los Alamos, New Mexico. This is a

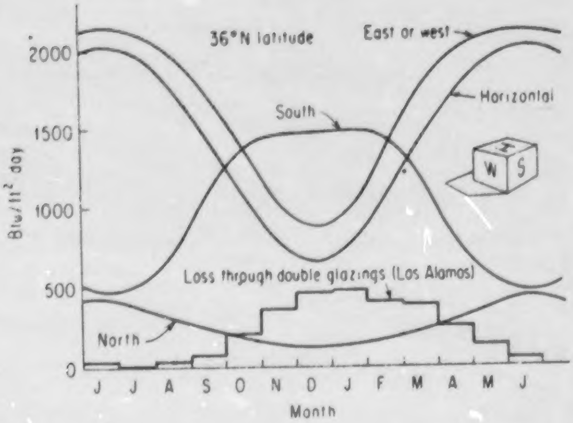

Figure 6-8: Clear-day solar gains through double glazing for various orientations for 36° north latitude. Solar gains are shown for different months of the year. The loss curve shown applies for a 6400°F-day climate (Los Alamos, New Mexico) for double glazing in any orientation. The net gain would be the difference between the total gain the the loss curve.

cold, clear climate at 36° N latitude, with a total heating load of approximately 6400°F days. Thus, even under these severe conditions one can see that there is abundant excess energy through south-facing double glazing on a clear day for use by the rest of the building.

It can also be noted that the solar energy incident on other surfaces of the building is totally out of phase with the requirements for heating. Glazing on the east or west face of the building contributes little to the winter heating of the building, but creates a major problem in terms of overheating during the summer months.

A normal approach used to obtain monthly averages of the solar radiation, accounting for actual cloud cover conditions, is to multiply curves such as those shown in the figure by a "cloudiness factor". This a a dubious approach because the effect of some clouds may be to decrease the direct component of the sunlight drastically and actually increase the diffuse component. The cloud factor does, however, give some quasiquantitative information about the obscration of the sun in different locations.

Window Overhangs

Although a wide variety of passive systems can be imagined for various applications, the main consideration here is the proper design of south-facing windows with overhangs for winter transmission of solar rays directly into a residence.

For the vast majority of locations in the United States, the latitudes range from 30° N to 45° N. As an example, consider a location at 38° N latitude. During the middle of winter, the sun rises in the southeast and sets in the southwest, reaching a maximum elevation above the southern horizon of about 30°. The shortest day is December 21, when the maximum elevation is 28.5°. In the summer time, however, the sun lies lowest in the southern sky at solar noon, when it lies about 70° to 75° above the southern horizon. At times other than noon, the sun is tilted further toward the northern sky. Therefore, it is clear that a south-facing window can be arranged with a suitable overhang so that the low-lying winter sun is admitted but the high summer sun is shaded from reaching the window. This is illustrated in Figure 6-9.

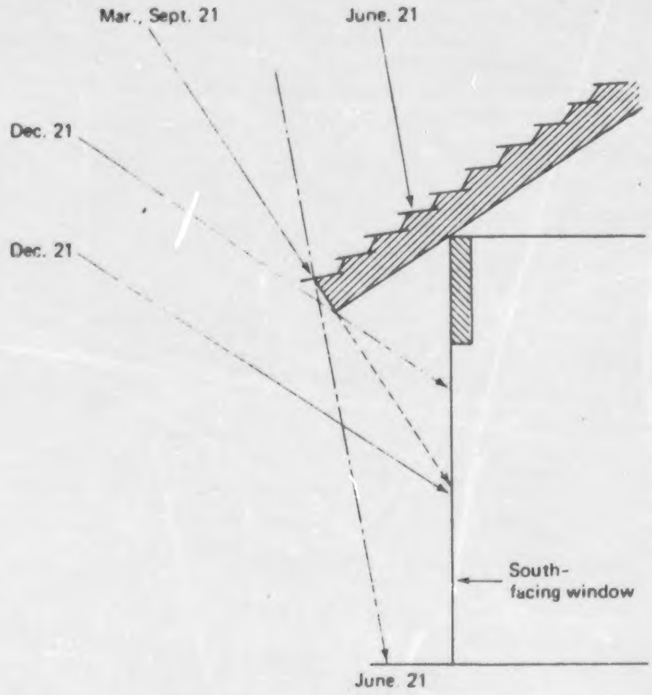

Figure 6-9: Diagram for passive systems

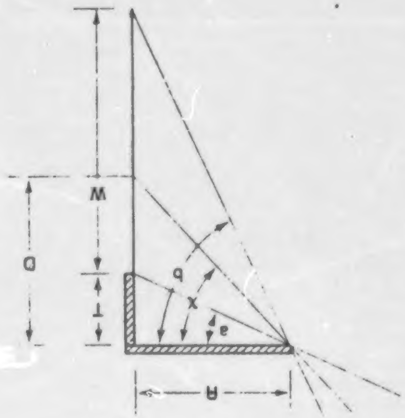

Figure 6-10: Angles for passive transmission.

Consider the diagram shown in Figure 6-10. The width of the overhang is R, the length of the top wall is T, and the window height is W. The angles for rays arriving at the top and bottom of the window are a and b, respectively.

The problem is to select values for R, T, and W to guarantee full winter illumination, but with suitable cut-off dates for the overhang to shield the window between spring and fall.

For most common home designs, $T + W = 8$ feet. To determine the dates at which full, partial, and zero illumination of the window occur, it is generally sufficient to consider the solar angles at 12:00 noon. This is because, between March 21 and September 21, the sun always lies further above the southern horizon at hours away from noon than at noon, and therefore an overhang that will shade the window at noon will shade it for hours other than noon. Conversely, between September 21 and March 21, the sun always lies lower in the southern sky at off-noon hours than it does at noon, and therefore a design that provides for full illumination at noon must provide for full illumination at off-noon hours during that half of the year.

At any hour of any day of the year, the line to the sun lies in a plane which makes an angle X with the horizontal plane. At solar noon, this angle reduces to $(90^\circ - L + d)$, where L is the latitude and d is the declination.

The angles a and b are defined by the equations:

$$\tan a = T/R \qquad\qquad \tan b = (T + W)/R.$$

For complete illumination of the window, we require $X < a$, and for zero illumination, $X > b$.

The days of the year when complete illumination first occur are determined by:

$$\tan a = T/R = \tan X,$$

and the days when zero illumination first occur are determined by:

$$\tan b = (T + W)/R = \tan X.$$

The fraction of the window illuminated is defined as:

$$f = \frac{W - (D - T)}{W}$$

It follows that:

$$f = \frac{\tan b - \tan X}{\tan b - \tan a}.$$

Heat Flow Through Windows

When a beam of solar radiation falls on a sheet of window glass, as shown in Figure 6-11, some of the radiant energy is reflected from the front and rear surfaces of the glass, some is absorbed as the radiation passes through, and some is transmitted to the glazed space. The quantitative values of these solar-optical properties - reflectance, ρ , transmittance, τ , and absorptance, a - vary with the incident angle θ between the incoming ray and the line, OP, normal (perpendicular) to the surface.

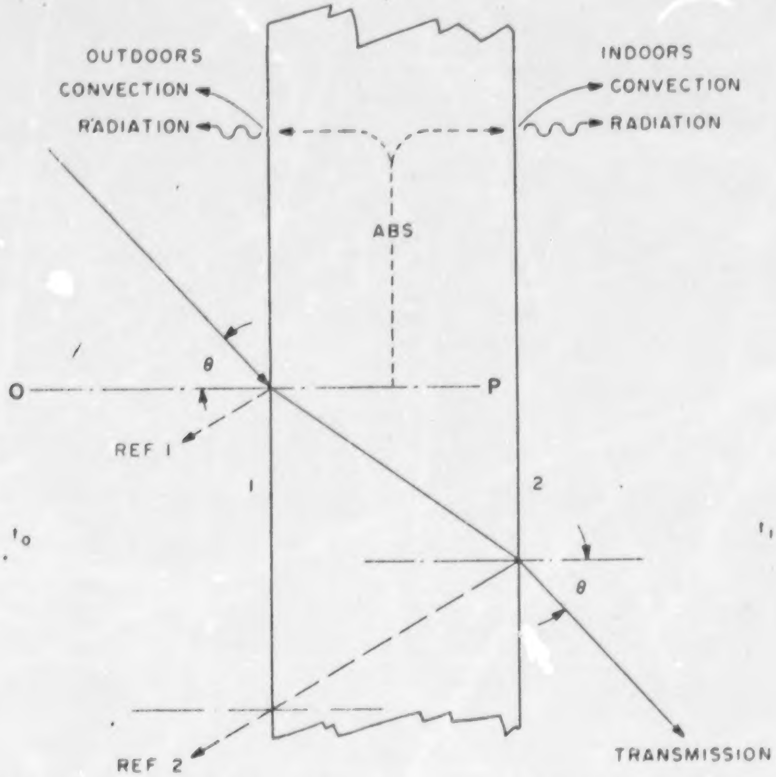

Fig. 6-11: Interaction of solar ray with window glass. Reflection occurs at first surface, 1, and second surface, 2; refraction towards the normal occurs at first surface, back to original direction at 2.

Windows, regardless of what the sun may be doing, conduct heat inwardly or outwardly, in response to temperature differences between indoor and outdoor air. The complete equation for heat flow through fenestration in winter is:

$$Q = \begin{matrix}\text{Btu}\\ \text{per}\\ \text{Hour}\end{matrix} = \text{Area} \times [SC \times SHGF - U \times (t_1 - t_o)]$$

Where U = overall coefficient of heat transfer, Btu/ (hr. ft^2F).

t_i, t_o = indoor temperatures, F.

A = area of glazed surface, ft^2

In summer, when t_o is higher than t_1, the second term in the equation becomes

$+ U(t_o - t_1)$.

The ASHRAE procedure for estimating solar heat gain assumes that there is, for all practical purposes, a constant ratio between the solar heat gain through any given type of fenestration (i.e., any light-transmitting opening in a building wall or roof, such as single or multiple sheet, plate or float glass, pattern glass, plastic panels, glass blocks, etc.) and the solar heat gain (under exactly the same solar conditions) through unshaded clear sheet glass (i.e., a reference glass). This ratio, called the shading coefficient (SC), is unique for each type of fenestration or each combination of glazing and shading device:

$$SC = \frac{\text{solar heat gain of fenestration}}{\text{Solar heat gain of double-strength glass}}$$

Figure 6-12 shows shading coefficients for a number of unshaded single and double glazings. This is shown on the following page.

The solar heat gain factor (SHGF) is the solar heat gain through the reference glass (i.e., clear, Grade A, double-strentgh glass with a transmittance of 0.87, reflectance of 0.08, absorptance of 0.05) for clear days when the latitude, date, and time are specified. The *ASHRAE Handbook of Fundamentals* gives solar heat gain factors.

HEAT CONTROL IN WINDOW SYSTEMS

There are a large number of methods available for controlling the heat transmission through windows, some of which have already been briefly discussed. Two additional methods have been used with some degree of success.

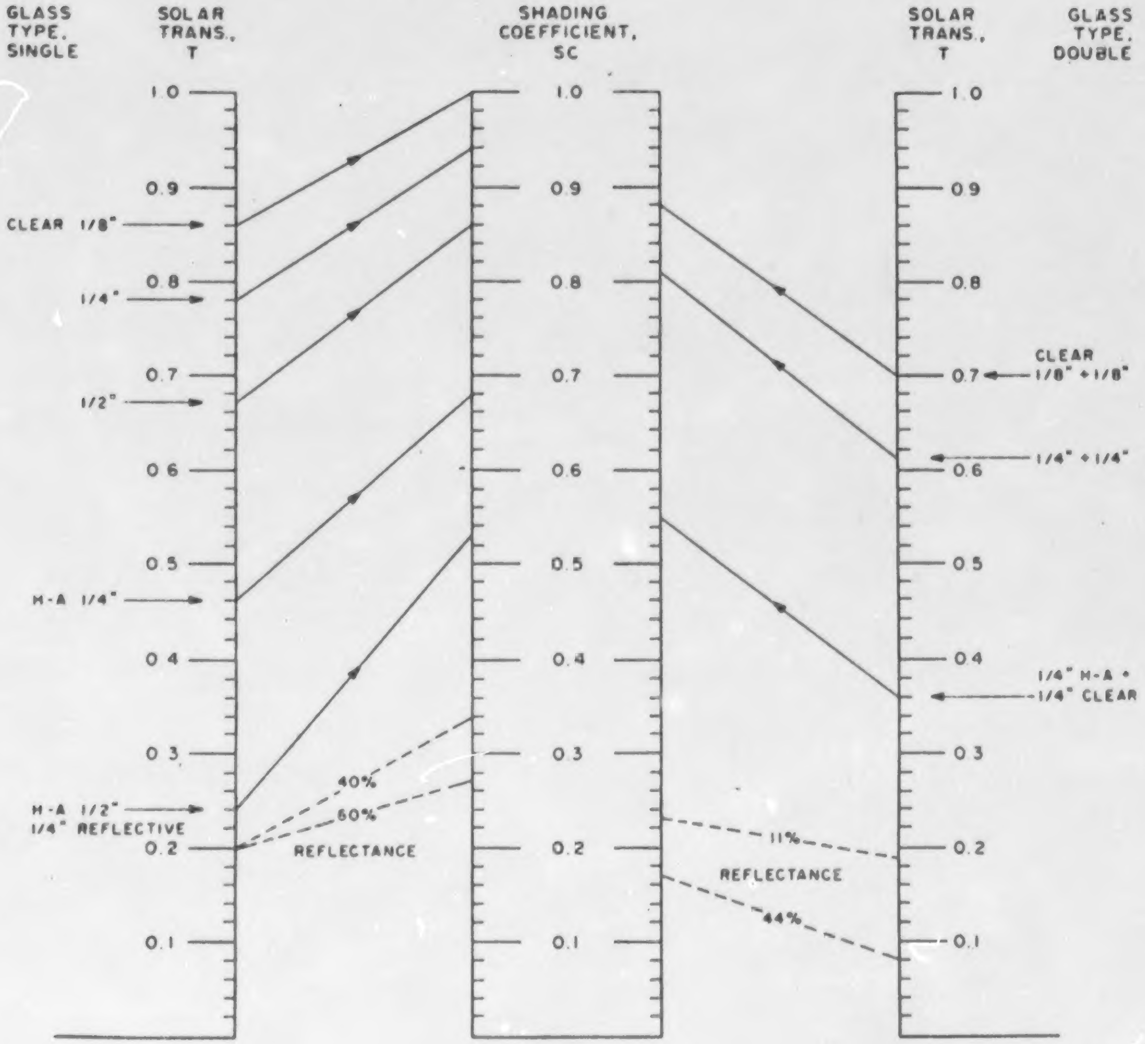

Figure 6-12: Shading coefficients vs. solar transmittance for single and double glazing (data from 1977 ASHRAE HANDBOOK OF FUNDAMENTALS).

Transparent Heat Mirrors

Architecturally, a window is a very complex building component which must perform multiple, often contradictory, functions. In order to function effectively in a passive solar heating role and maximize beneficial heat gain, the window must be highly transparent to the incident solar spectrum, but must also have a high resistance to all thermal loss mechanisms.

One approach to reducing thermal losses while maintaining high solar transmission involves the use of thin, transparent optical films which are reflective to the long-wave infrared radiation emitted by room temperature surfaces (low emissivity). These thin films, known as "heat mirrors," can be applied to glass or plastic glazing material, and, depending on the application, will reduce thermal losses by 25 to 75%. While the potential savings are quite large, there are a number of constraints and obstacles, both technical and institutional in nature, that must be overcome before transparent heat mirrors can be successfully commercialized.

The Energy-Efficient Windows Program at the Lawrence Berkeley Laboratory, with funding provided by the U. S. Department of Energy, is in the process of supporting research, development and demonstration activities to assist in the commercialization of heat mirror products.

Heat mirror coatings may be applied directly to glass and installed in new and retrofit applications, or they may be applied to thin plastic films and then glued to existing windows, much as solar control films are applied. A variety of different window configurations utilizing heat mirrors are possible. Several are shown in Figure 6-13, with associated U values and solar transmittance properties. Since there is a tremendous inventory of single-glazed windows in the United States, retrofit options for single-glazed windows should present good sales opportunities.

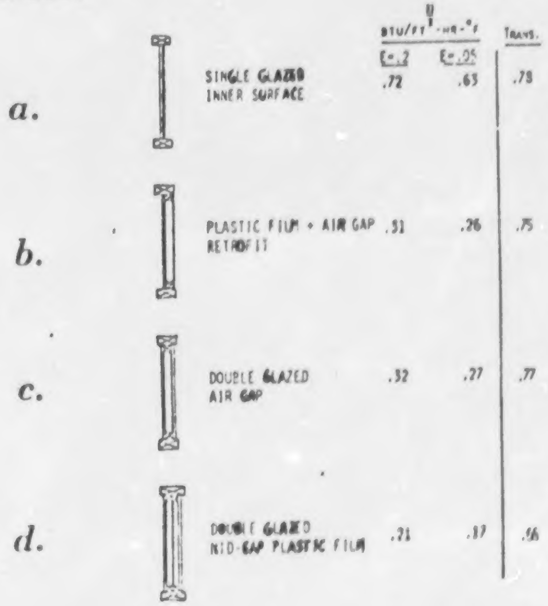
U
BTU/FT²-HR-°F
TRANS.
E=.2
E=.05
a.
SINGLE GLAZED
INNER SURFACE
.72
.63
.78
b.
PLASTIC FILM + AIR GAP
RETROFIT
.31
.26
.75
c.
DOUBLE GLAZED
AIR GAP
.32
.27
.77
d.
DOUBLE GLAZED
MID-GAP PLASTIC FILM
.21
.17
.56

Figure 6-13: Heat Mirror Applications

Figure 6-13a shows nominal performance values for a heat mirror applied directly to the interior of an existing window. The nominal U value is reduced from 1.14 Btu/ft^2 hr ^{o}F to a range of 0.72 to 0.63 depending upon the emissivity of the heat mirror surface. Note that the heat mirror must face the room side to be effective, and must therefore be adequately protected from abrasive and corrosive stresses.

Figure 6-13b shows a generic configuration for a window retrofit, which was extensively explored in the Suntek contract. The plastic film substrate with a heat mirror coating is glued to a plastic or metal frame, which is in turn attached to the glass in an existing window. This can be permanently attached with adhesives or attached with a removable mechanism such as a magnetic seal. The heat mirror surface is protected by facing the air gap.

If the unit does not hermetically seal to the glass and incorporate a desiccant, there are potential condensation problems. Rigid plastic may be substituted for the polyester film if the "soft" characteristic of this retrofit is not acceptable. By creating an air space and adding a heat mirror at the same time, it drops the thermal loss of a single-glazed window by approximately 75%

Factory assembled double glazing could incorporate a heat mirror surface applied directly to the glass, facing the air space or applied to plastic and then laminated to glass (Figure 6-13c). The resultant U value is lower than that to be expected from triple glazing, and may thus represent an attractive option.

A more attractive approach to modifications of factory-assembled double-glazing would add the polyester film with heat mirror to the center of the double-glazed unit (Figure 6-13d). If the plastic is coated on both sides with a heat mirror (or if a suitable IR transparent plastic with a single heat mirror coating is used), the window will exhibit an extremely low rate of thermal transfer, approximately 0.17 to 0.21 Btu/ft^2 hr. ^{o}F, depending on the heat mirror emissivity (0.05 to 0.20).

A variety of other heat mirror applications are possible. Both interior and exterior storm windows might incorporate heat mirror coatings, but the reduction in U value will depend on heat mirror emissivity as well as on the degree of air movement in the air space that is created if the storm window is not very tight fitting. Several different types of single and multilayer roll-up shades are being introduced to the marketplace and these typically incorporate one or more metallized plastic layers to reduce thermal transfer. With the use of transparent heat mirrors, these devices could maintain their good thermal performance and still provide some light and view. In fact, a transparent heat mirror provides the option of turning virtually any smooth, colored surface in a building into a thermal heat reflecting layer and the performance of drapes, venetian blinds, shutters and other window accessories might be improved accordingly.

In each case, ultimate heat mirror cost and performance characteristics would appear to be crucial factors in determining tradeoffs. In many circumstances, the advantage of light transmission through heat mirrors may not justify the added cost compared to much cheaper light reflecting metallized plastics.

Beadwalls

The transparent and reflective qualities of glass make it a unique, relatively maintenance-free building material. Many large buildings use it as the main enclosure material, but heat gains and losses through large glass areas must be controlled. Curtains and blinds shield these areas from sun in summer to reduce heat gain, but do little to prevent winter or lighttime heat loss.

The Beadwall (U. S. Patent 3,903,665) is a curtaining device for transforming a clear glass wall into an opaque, well-insulated wall and then back again. A granular insulating material is blown from a storage container into a cavity between two glazings to minimize heat loss. When the sun is shining, the insulator is drawn from the cavity under a vacuum and returned to its container, so the glazings are once again translucent (see Figure 6-14 on the following page).

Insulating Materials: A variety of granular materials were tested. Sawdust and vermiculite were too dusty and clung to glass; wood chips would not blow, and clogged transport ducts; popcorn was greasy. Expanded polystyrene beads 1/8" - 3/16" in diameter were found most suitable. Polystyrene beads have a U value of about 0.30/inch thichness. Obviously, the thicker the cavity between glazings, the better the insulation.

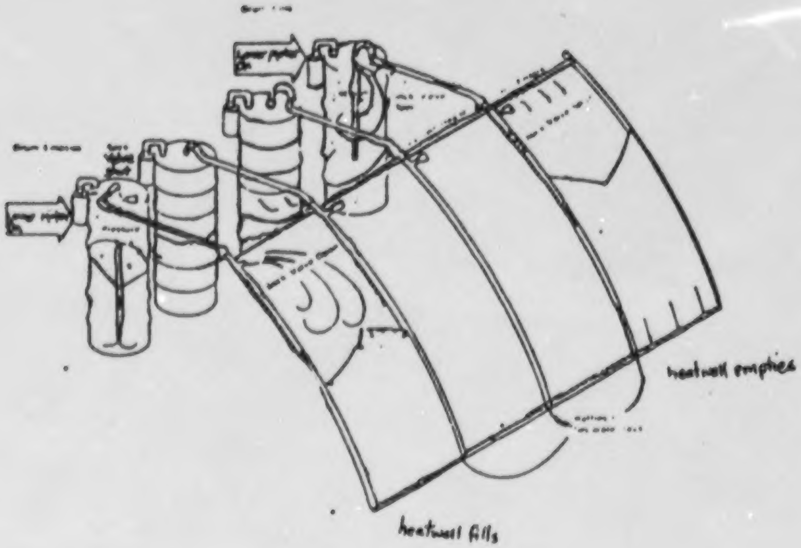

Figure 6-14: Schematic Diagram of Beadwall System

After cycling polystyrene beads through the system a number of times, they become charged with static electricity and cling to glazing, ducts, valves, and storage containers. Sodium acetate dissolved in glycerin is an effective antistatic agent, but its life span is a few months. UV radiation absorbers and antioxidants are also added to the solution to prolong bead life.

The continual tumbling of the beads and the exposure of new surfaces to the sun further extend their life.

Panel Glazing: A wide range of glazing materials can be used successfully in the fabrication of Beadwall panels. Glass is the most beautiful material. Single-strength glass, 3/32" thick and 1/8" double-strength glass both failed to withstand the internal pressures of a vented Beadwall panel. 3/16" float glass and 1/4" plate glass have both been used successfully as glazing materials. However, should the panel vents ever become clogged so that internal pressure builds up, the panel will explode into thousands of dangerous glass splinters. Therefore, it is recommended that tempered safety glass be used to minimize this danger.

Acrylic glazing materials may also be used, but they are more expensive and the static problem is more severe. Fiberglass is the least expensive glazing material. However, it is not transparent and the bead flow patterns are not as visible. Fiberglass and acrylic materials are not rigid enough to withstand the pressure changes within the panel. Ties and spacers are needed for these materials to keep the glazings together when the panels fill and to keep them apart when they drain.

Almost any glazing details will work when making the Beadwall panel, but it is essential that everything be weather-tight. Water and beads do not mix; if they should, the entire system will clog and no longer function. The panels must be vented to the atmosphere to relieve the pressure of incoming beads and air when the panels fill, and to replace the evacuated air when the panels empty. The panels should be vented to the outside air to minimize condensation within the panel. The blower motors should also draw outside air. (Insufficient venting can cause the panel to rupture).

Panels less than 5' in height may be successfully filled and drained from a single outlet at the bottom of the panel, which makes ducting and valving easier. Panels taller than 5' must be filled from the top and drained from the bottom. The angle of repose of polystyrene beads is about 30°. Thus, tall, narrow bead storage containers and panels are easier to fill and empty than low, wide ones. Generally, the larger the panel, the lower the system cost. The length of bead ducting, and number of blowers and storage containers stay relatively the same.

THERMAL STORAGE

It is easy for large sunlit windows to admit so much solar energy that the building overheats even on winter days. One solution to this problem, and the problem of nighttime heat losses, is to provide a means for storing the excess heat for later use, to offset the use of conventional fuels. The simplest form of heat storage utilizes the structure of the building itself - its walls, floors, ceilings, and interior partitions. By employing dense materials such as concrete, adobe, brick, and containers of water, one can increase the building's ability to absorb and release heat without varying much in room temperature.

Different materials absorb different amounts of heat while undergoing the same temperature rise. The ability of a material to store heat is expressed in terms of energy per unit mass, or (more usefully) in terms of energy per unit volume.

- Specific heat or heat capacity (Btu/lb-°F), is the heat absorbed by a pound of a material as its temperature rises one degree F. Values of specific heat for a number of materials are given in Table 6-1. Specific heats vary with temperature; those tabulated are for room temperature unless otherwise noted.

- Volumetric heat capacity (Btu/ft^3-°F), is the heat absorbed by one cubic foot of a material as its temperature rises one degree F. It is the product of the density of the material times its specific heat. Table 6-1 also contains volumetric heat capacity values.

To store large amounts of heat in a given volume, one should use materials that have high heat capacities.

To be effective as a heat storage element, a wall must not only have high thermal heat capacity, but it should also have a high thermal conductivity, k, since the deeper portions of the wall cannot participate in the charging and discharging cycle if they are isolated from the room by a layer of low-thermal-conductivity material. Some thermal conductivity values are given in Table 6-2, shown in the following pages. Since materials which have a high density also usually have high thermal conductivity, it follows that wall materials, which are good insulators, are poor for thermal storage. Materials such as styrofoam and fiberboard are nearly worthless for heat storage walls, wood is moderately poor, and concrete, rock, brick, and adobe are relatively good.

Thus, the very properties which make a wall perform well as an (interior) thermal storage element make it perform poorly as an (exterior) insulating element. Unfortunately, common construction practice is to make interior partitions of lightweight frame construction and place the more massive construction (if used at all) in exterior walls. Frequently, the most massive elements are placed outside the thermal insulation; for example, the use of a brick exterior over an insulated frame wall.

Table 6-1: Heat Capacities of materials at room temperature
(ASHRAE Handbook of Fundamentals)

	Specific Heat	Density		Volumetric heat capacity (no voids)	
	Btu/lbF and cal/gC	lb/ft^3	kg/m^3	Btu/ft^{3}F	kcal/m^{3}C
Water	0.999	62.3	998	62.2	997
Mild steel	0.12	489	7830	58.7	940
Scrap iron	0.11	489	7830	53.8	863
Copper	0.092	556	8900	51.2	819
Yellow brass	0.09	519	8320	46.7	748
Silica	0.316	140	2240	44.2	709
Paraffin	0.69	56	899	38.6	620
Asbestos fiber	0.25	150	2400	37.5	601
Aluminum	0.214	171	2740	36.6	586
Rock, typical	0.21	165	2640	34.7	550
Marble	0.21	162	2600	34.0	545
Rubber	0.48	68.6	1100	32.9	526
Concrete	0.23	140	2240	32.2	516
Glass, flint (lead)	0.117	267	4280	31.2	500
Cotton fiber	0.319	95	1520	30.3	486
Chalk	0.215	143	2290	30.8	493
Hemp fiber	0.323	93	1490	30.0	481
Rock salt	0.219	136	2180	29.8	477
Porcelain	0.18	162	2600	29.2	467
Asphalt	0.22	132	2120	29.0	465
Glass, common	0.18	154	2470	27.7	444
White oak	0.570	47	750	26.8	429
Wool fiber	0.325	82	1310	26.7	427
Tin	0.056	455	7290	25.5	408
Brick, building	0.20	123	1974	24.6	395
Firebrick	0.198	112	1790	22.2	355
Paper	0.32	58	930	18.6	297
Sand	0.191	94.6	1520	18.1	290
White pine	0.67	27	430	18.1	290
White fir	0.65	27	430	17.6	281
Clay	0.22	63	1010	13.9	222
Gypsum (plasterboard)	0.26	50	802	13.0	209
Wood ashes	0.20	40	640	8.0	128
Asbestos insulation	0.20	36	580	7.2	115
Cork, granulated	0.485	5.4	87	2.6	42
Cellulose	0.32	3.4	55	1.1	17
Polyurethane insulation	0.38	1.5	24	0.6	9

Note: Values given are for average humidity. Thermal properties of wood, concrete, and other materials will vary with moisture content.

Table 6-2: Thermal Conductivity of Materials

		Thermal conductivity		
Material	*Temperature, °C*	*cal cm/sec C°cm^2*	*W cm/C°m^2*	*Btu in./h F°ft^2*
Metals				
Aluminum	100	0.49	20500	1130
	200	0.55	23000	1590
	400	0.76	31800	2210
	600	1.01	42300	2932
Brass	0	0.25	10400	720
Copper	20	0.934	39300	2711
	100	0.908	38100	2640
	300	0.89	37200	2580
Magnesium	20	0.37	15400	1070
Steel	18	0.115	4800	330
	100	0.107	4500	310
Nonmetals				
Asbestos fiber	500	0.00019	8.0	0.55
Brick	20	0.0015	62	4.3
Concrete	20	0.00071	30	2.0
Cotton wool	20	0.000043	1.8	0.12
Diatomaceous earth	20	0.00013	5.4	0.38
Granite	20	0.0045	188	13
Glass	20	0.0017	71	5.0
		−0.0025	−100	−7.2
Glass wool	20	0.000081	3.4	0.24
Infusorial earth	100	0.00034	14.0	1.0
	300	0.00040	17.0	1.2
Magnesia brick	500	0.0050	210	14.0
Plaster of Paris	20	0.00070	29.0	2.0
Sand, dry	20	0.00093	39.0	2.6
Soil, dry	20	0.00033	14.0	0.96
wet	20	0.0010	42.0	2.9
Wood, across grain	20	0.00010	4.2	0.29
		−0.00030	−12.6	−0.87
Gases				
Air	20	0.000057	2.4	0.13
Carbon dioxide	20	0.000031	1.3	0.07
Helium	20	0.000339	14.2	0.79
Hydrogen	100	0.000369	15.4	0.86

Thermal Admittance

The property of thermal admittance of a wall is a measure of the ability of the wall to absorb and store heat during one part of a cycle and then to release the heat back through the same surface during the second part of the cycle. Thus the property of thermal admittance is coupled to the cyclic nature of the give and take of heat at the surface of the wall. Technically, the thermal admittance is the ratio of the amplitude of a sinusoidal wave of heat flow to the amplitude of the corresponding sinusoidal wave of surface temperature.

In the illustration of Figure 6-15, the wall surface tempreature varies sinusoidally around a constant average value and the heat flow into the surface varies sinusoidally around an average value of zero. The magnitude of the temperature cycle is $\Delta T_s/2$ so that the wall surface temperature varies from $\overline{T}_s + \Delta T_s/2$ to $\overline{T}_s - \Delta T_s/2$ (where $\overline{T}_s$ is the average storage surface temperature) and the magnitude of the heat flow is Δq so that the heat flow varies from $+ \Delta q/2$ (into the wall) to $- \Delta q/2$ (out of the wall). Note that the two sinusoidal waves are slightly out of phase. Typically the temperature wave lags the heat flow wave by one-eighth of a cycle (45 angular degrees) for a thick wass, and by one-fourth of a cycle (90 angular degrees) for a very thin wall.

The thermal admittance, a, is simply the ratio $\Delta q / \Delta T_s$. For a thick wall it is given by the formula:

$$\frac{\Delta q}{\Delta T_s} = \sqrt{\frac{2\pi k \rho c}{\rho}} = \qquad (6\text{-}1)$$

where ρ is the period of the sine wave oscillation.

Generally, we are most concerned with cyclic oscillations which have a period of 1 day or 24 hours. This implies a charging of the wall during the day and a discharging of the wall at night. The fact that the wave is not truly sinusoidal is not of great consequence. First-order effects can be obtained by considering a pure sine wave solution which leads to simple answers.

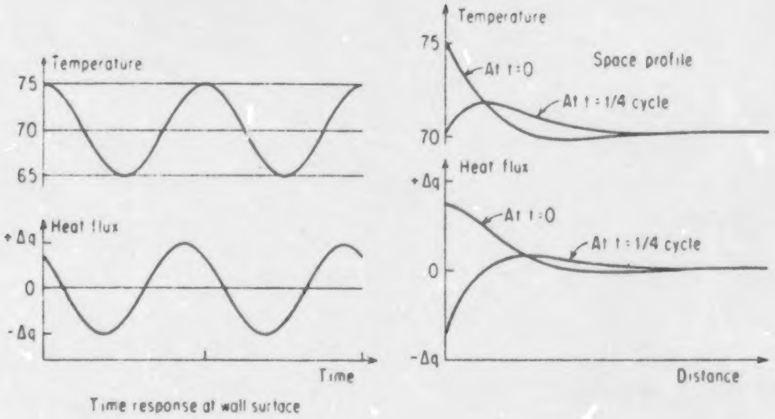

Figure 6-15: Thermal response characteristics of a thick wall. The upper curves show the time response at the wall surface. The temperature curve lags the heat flux curve by one-quarter cycle. The lower curves show the space profiles of both temperature and heat flux at two times; the curve marked T=0 is a time at which the temperature peak is at a maximum, and the curve marked T = 1/4 cycle is at a time when the temperature difference is 0 and decreasing.

How Much Heat is Stored? The total heat Q stored during a half cycle when q is a positive is obtained by multiplying the peak heat flux by p/2 π .

$$\frac{Q}{\Delta T_s} = \left(\frac{\rho}{\pi}\right)\left(\frac{\Delta Q}{2\,\Delta T_s}\right) \qquad (6\text{-}2)$$

For a thick wall, the formula is:

$$\frac{Q}{\Delta T_s} = \sqrt{\frac{pk\,\rho\,c}{2\,\pi}} \qquad (6\text{-}3)$$

How Thick Should the Wall Be? Consider what happens inside the wall. At each point the temperature variation is sinusoidal and the heat flow through any plane parallel to the surface is also sinusoidal. The magnitude of the sine wave decreases rapidly as the distance from the surface increases. The phase of the sine wave also changes with distance into the wall. At some point, well into the wall, the sine waves are completely out of phase with the sine waves at the surface. Thus the deeper portions of the wall can be counteracting the effect of storage in the outer portions of the wall.

The solution of the problem of a wall of finite thickness is more complicated than for a wall of infinite thickness. The answer is illustrated in the graph of Figure 6-16, which shows the ratio of a wall of finite thickness to a wall of infinite thickness. This graph shows that there is an optimum thickness for which the thermal admittance is the greatest. This optimum thickness is given by the following formula:

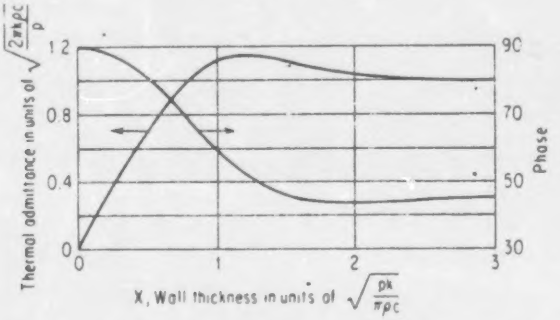

Figure 6-16: Thermal admittance of a finite wall insulated on the back side.

$$\ell_{\text{optimum}} = 1.18\sqrt{\frac{pk}{\pi\rho c}} \qquad (6\text{-}4).$$

Thermal Admittance of Common Materials: Table 6-3, on the following page, can be used to estimate the heat stored in building materials based on two considerations:

1. Location of the material relative to the sun radiation;

2. Properties of the wall material.

Thermal Storage Walls

Thermal storage walls fall into three general categories: those utilizing a massive wall to store heat - these are known as Trombe walls; those utilizing a water wall to store heat; and the more experimental type in which heat is stored in eutectic salts or salt hydrates. Because Trombe walls are the most used type of thermal storage wall, much of the discussion will focus on them. Five elements of a thermal storage wall can be identified; glazing, air space between glazing and wall, the mass or storage wall, vents, and roof overhang.

TABLE 6-3: THERMAL ADMITTANCE OF VARIOUS MATERIALS

				Material					
Name	Symbol	Formula	Units	Gravel and sand concrete	Limestone rock	Brick	Wood (pine)	Dry sand	Adobe
Density	ρ	—	$\frac{lbs}{ft^3}$	144	153	112	31	95	120
Specific heat	c	—	$\frac{Btu}{lb \cdot °F}$	0.19	0.22	0.22	0.67	0.19	0.20
Thermal Conductivity	k	—	$\frac{Btu \cdot ft}{ft^2 \cdot °F \cdot h}$	1.05	0.54	0.40	0.097	0.19	0.332
Thermal admittance of infinite wall*	a	$\sqrt{\frac{2\pi k\rho c}{p}}$	$\frac{Btu}{ft^2 \cdot °F \cdot h}$	2.74	2.18	1.61	0.60	0.95	1.44
$\frac{\text{Energy stored daily}}{\Delta T_{surface}}$ (infinite wall)	$Q/\Delta T_s$	$\sqrt{\frac{pk\rho c}{2\pi}}$	$\frac{Btu}{ft^2 \cdot °F}$	10.4	8.3	6.1	2.6	3.6	5.5
Wall thickness for maximum heat storage	$l_{optimum}$	$1.18\sqrt{\frac{pk}{\pi\rho c}}$	in	7.6	5.0	5.0	2.5	4.0	4.6
Admittance of air film and wall in series	$q/\Delta T_r$	See text	$\frac{Btu}{ft^2 \cdot °F \cdot h}$	1.11	1.04	0.92	0.57	0.70	0.67
$\frac{\text{Daily stored energy}†}{\Delta T_{air}}$	$Q/\Delta T_r$	$\frac{p\ \Delta q}{\pi\ \Delta T_r}$	$\frac{Btu}{ft^2 \cdot °F}$	4.1	3.9	3.5	2.1	2.6	3.3

*In the table the value of sinusoidal period p is 24 h.

†For wall of thickness $l_{optimum}$, $U_{air\ sur}$ = 1.5 Btu/h · °F · ft² (1 Btu = 1.055 kJ, 1 ft² = 0.093 m², 1 lb = 0.454 kg). For $l_{optimum}$ see Eq. 6-4.

During the day, sunlight strikes the double glazing on the thermal storage wall and some percentage of that light passes through the glazing. Most of the light penetrating the glazing is absorbed by the dark surface of the mass wall. In an unvented thermal storage wall, this heat goes into the mass wall. In a vented thermal storage wall, in addition to heat moving into the mass wall, air between the glazing and wall heats up and moves directly into the building in a convective loop. In either case (vented or unvented thermal storage walls), heat is absorbed into the mass wall, where it is stored and slowly moves through the wall in a conductive wave. The thicker the wall, the more heat it can store and the longer the conductive wave takes to move across it. For a very thick wall (around 24 inches), there will be almost no variation of temperature on the inside, while for a thinner wall (8 to 14 inches) the amplitude of the wave will be pronounced, the wave will move faster, and most of the heat will be provided to the living space in the evening (when it is often most needed).

Mass Wall: The mass wall is the most crucial component of a Trombe wall type thermal storage wall. In it, the solar heat will be stored and transmitted to the inside of the building. The material used for a mass wall is, therefore, very important. Also important with a mass wall is the surface exposed to the sun. It is necessary that the surface of the mass wall absorb nearly all the light energy passing through the glazing. To do this, the surface of the mass wall should be a dark color. If using paint on the mass wall, it should be black or a very dark color, and should be able to withstand the high temperatures reached in a Trombe wall collector. Darkening agents other than paints may be used, depending on the wall material. Wood stains have been used to darken adobe and concrete block. Cement stucco can easily be darkened with added pigments. Counter to much previously published information, there is apparently very little difference in absorption between flat and glossy paints, glossy paints being, in fact, better, as they tend to pick up less dirt and dust.

In selecting the material for a mass wall, two considerations should be made: cost and thermal characteristics. With thermal characteristics, the interest is in (1) how much heat a material can store, and (2) how rapidly that heat can be transmitted (by conduction) through the material and released to the inside air. These characteristics are determined by four physical properties of a material: density, conductivity, specific heat. and heat capacity.

In addition to the massive building materials (concrete, brick, stone, adobe, etc.), there are other possibilities for a thermal storage wall. Water has been used extensively as a heat storage medium, and in fact, is in many applications superior to mass walls. Salt hydrates also have great potential in storing heat for solar applications.

Performance Prediction: The monthly Solar Load Ratio (SLR) provides an empirical means of estimating monthly solar and auxiliary energy requirements. The monthly Solar Load Ratio is a dimensionless correlation parameter defined as follows:

$$\text{SLR} = \frac{\text{Monthly solar energy absorbed on the thermal storage wall surface}}{\text{Monthly building load (including the wall steady-state losses in the absence of solar gains)}}$$

The numerator is equal to the product of the total solar collection wall area times the monthly solar energy transmitted through 1 square foot of south glazing times the wall absorptance. The denominator is equal to the building loss coefficient (including the steady-state conduction through the south solar collection wall) times the monthly heating degree days.

The SLR can be expressed as follows:

$$\text{SLR} = \frac{\begin{array}{l}\text{Collector}\\ \text{wall area} \times \text{absorptance}\end{array} \times \begin{array}{l}\text{monthly solar energy}\\ \text{transmitted through}\\ \text{the glazing}\end{array}}{\begin{array}{l}\text{Modified building}\\ \text{loss coefficient}\end{array} \times \text{monthly degree days}}$$

Step 1 - Determine the building heat-loss coefficient (Btu/day-$^{\circ}$F) and get a modified building loss coefficient by adding to it the term (24) (solar wall area) (U_w) where U_w is taken from the following table:

Wall type	Plain double glazed	With R-9 insulation added from 5:00 p.m. to 8:00 a.m.
Water wall	0.33	0.18 Btu/hr-ft^2-$^{\circ}$F
18-in. Trombe wall	0.22	0.12 Btu/hr-ft^2-$^{\circ}$F

The value of U_w is the steady-state conduction coefficient of the combined wall, glazing, and insulation, averaged over the day.

Step 2 - Determine the SLR for each month of the year. Solar radiation values generally available are measured on a horizontal surface, whereas the values required in order to determine the SLR are the actual solar radiation transmitted through the vertical south-facing surface. It is given by (for angles, in degrees) for vertical walls with double glazing:

$$\bar{I}_{vert} = [0.2260 - 0.002512\,(L - \delta_s) + 0.0003075\,(L - \delta_s)^2] \times \overline{H_h}$$

Where: $\bar{I}_{vert}$ is the actual solar radiation transmitted through the vertical south-facing surface:

L is the local latitude

δ_s is the solar declination

$\overline{H_h}$ is the monthly mean of daily total radiation on a horizontal surface.

If the building does not face due south, then this equation cannot be used. It will be necessary to make another correction for building orientation.

Step 3 - Determine the monthly solar heating fraction f_s for each month of the year based on the values of SLR computed in Step 2 using the equation below:

$$f_s = a_1 \, (SLR) \qquad SLR < R$$

$$F_s = a_2 - a_3 e^{-a_4 \, (SLR)} \qquad SLR > R$$

such that the values are equal at SLR = R. The values of the parameters in the function give a minimum least-square error in the annual heating fraction. The values of the least-square coefficients are:

Wall Type	R	a_1	a_2	a_3	a_4
Water wall	0.8	0.5995	0.0149	1.2600	1.0701
Night-insulated water wall	0.7	0.7642	1.0102	1.4027	1.5461
Masonry wall	0.1	0.4520	1.0137	1.0392	1.7047
Night insulated masonry wall	0.5	0.7197	1.0074	1.1195	1.0948
Direct gain	0.1	0.6182	1.0097	1.0710	1.2208
Night-insulated direct gain	0.6	0.8865	1.0028	1.2646	1.6467

*PASSIVE PERFORMANCE ANALYSIS

To determine the approximate energy savings which can be expected from a passive solar design, the following calculation procedure can be used. This method simplifies many difficult computations and, as a result, a number of assumptions have been incorporated. The most important are listed below:

1. The system requires 45 Btu/°F of thermal storage for each SF of glazing - (e. g., 9 inches of water or 19 inches or concrete for a thermal storage wall).
2. The south-facing glass is double glazed.
3. The temperature range in the building is allowed to fluctuate between 68° F and 75° F.
4. The night insulation has an "R" value of 9 and is drawn from 5pm to 8am.

With these assumptions, the following procedure provides a quick estimating metiod.

1. Calculate the Building Skin Conductance. Using areas measured from plans and "U" values for typical ASHRAE calculations, compute the conductance through the building envelope, excluding the passive collector area.[1] (e. g., south window for direct gain, Trombe wall, etc.)

SURFACE TYPE	AREA		"U" VALUE		A x U
Walls[1]		x		=	
Windows[1]		x		=	
Roof		x		=	
Floor		x		=	

Building Skin Conductance = Btu/°F/hr.

2. Calculate infiltration losses. Using standard ASHRAE methodology, compute the heat loss to changes in air inside the house.

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INTERIOR VOLUME		AIR CHANGE		CONSTANT[2]		
Cubic feet	x	A/c	x	0.018	=	Btu/°F/hr.

[2] This constant is the product of the specific heat and the density of the air.

3. Determine the Building Loss Coefficient (BLC)

Sum up the building skin conductance and infiltration and multiply by 24 hours.

Building Skin Conductance	(BTU/°F/HR)
+ Infiltration	(BTU/°F/HR)
Total	(BTU/°F/HR)
x 24	(HR)
	(BTU/DD)

4. Determine the Load Collector Ratio (LCR). This is done by dividing the Building Loss Coefficient (BLC) by the area of the passive solar collector. This area would be the actual aperture tha the sun can come through:

$$\frac{\text{Building Loss Coefficient (BTU/DD)}}{\text{Solar Collector Area (SF)}} = \text{Load Collector Ratio (BTU/DD/SF)}$$

5. Having determined the Load Collector Ratio (LCR) go to Table 1 and locate the city closest to your location. Select the line with the passive solar system being utilized.

DG = for direct gain or attached sunspace
DGNI = the above systems with night insulation
TW = for thermal storage wall (masonry)
TWNI = the above with night insulation
WW = for thermal storage wall (water) or thermal storage roof
WWNI = the above systems with night insulation

On the appropriate line find the LCR number you have calculated and read up to the Solar Heating Fraction (SHF). If the LCR is between the two numbers listed, interpolate to arrive at the proper SHF.

Load Collector Ratio (LCR) ______________ Btu/DD/SF

To interpolate - list the two numbers which bracket the load collector ratio you have calculated and find the difference between the two:

First number from table ______________

Second number from table ______________

Difference # 1 ______________

-determine the difference between the LCR you have calculated and the first number from the table:

First number from table ______________

calculated LCR - ______________

difference # 2 ______________

-calculate the ratio between the two differences:

$$\frac{\text{difference \# 2}}{\text{difference \# 1}} = \text{interval ratio}$$

-determine the interval between the two SHF which correspond to the two LCR numbers from the tables:

SHF for first number from table: ______________

SHF for second number from table: - ______________

difference # 3 ______________

-using the interval ratio, determine the SHF interval which corresponds to the location of the calculated LCR between the two table numbers:

Difference # 3 x interval ratio = SHF interval
SHF for first table number
final SHF

______________ x ______________ = ______________
+ ______________
______________ final SHF

6. The Solar Heating Fraction (SHF) is the portion of the building envelope heat loss which is supplied by the passive solar system. To determine the amount of auxiliary heat required for the remainder of the heating load (Auxiliary Heating Fraction or 1=SHF), the following computation is utilized:

Annual Heating Load (AHL) =
(Aux. Heat Fraction) x (Building Loss Coefficient) x (Heating Degree Days)*

* For heating degree days, use values obtained from the weather service closest to the site or the nearest city from the list included in the State Summary.

7. The AHL is the approximate quantity of energy for the entire year that is supplied by the auxiliary heating. In order to facilitate comparison between buildings and the guidelines presented later, the AHL is converted to Btu/SF/YR levels by dividing AHL by the floor area of the building being heated.

$$\text{Annual Energy Use Index (AEUI)} = \frac{\text{Annual Heating Load}}{\text{Building Floor Area}}$$

8. The form in which the proposed Building Energy Performance Standards (BEPS) are presented are also budgets of Btu/SF/YR. However, this Btu number is the actual consumption of energy supplied to the building and, therefore, must take into account the efficiency of the mechanical system.

To convert the AEUI to an energy budget:

$$\text{Energy Budget} = \frac{\text{Annual Energy Use Index}}{\text{Mechanical Plan Efficiency*}}$$

* The efficiency of the system can usually be obtained from the manufacturer or a local service company for the equipment being considered.

9. To arrive at an estimate of the annual fuel consumption in actual fuel units, simply divide the AHL (step 6) by the mechanical plan efficiency and the appropriate conversion factor listed below:

$$\text{Annual Fuel Requirement} = \frac{\text{Annual Heating Load}}{\text{Mechanical Plan Efficiency x Conversion Factor}}$$

FUEL UNITS	BTU'S
1 gal. of heating oil	138,000 (average)
1 cu. ft. of gas	1,000 (average)
1 KWH of electricity	3,413

It should be reiterated that these calculations are for simple and quick estimates and should not be used as a final design tool. To produce effective passive solar systems, the designer must use precise computations along with the exact climatic data for the specific site.

To analyze a passive solar house, it always helps to have some guidelines by which to judge the performance. Past experience indicates that the following energy consumption levels are typical:

6-8 Btu/SF/DD - a well insulated house using conventional heat

3-4 Btu/ST/DD - a good passive solar house

1-2 Btu/SF/DD - an excellent passive solar house

These figures give a good indication of the type of performance that can be expected. A "good" passive solar house can save, on the average, 50% of the annual fuel consumption of a well-insulated home with conventional heat. By converting these figures into energy budgets, the following table, 6-10, gives approximate heating loads for each listed degree-day climate.

Energy Use Index (EUI) MBTU/SF/YR	Heating Degree Days									
	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
Well insulated conv. house	6-8	12-16	18-24	24-32	30-40	36-48	42-56	48-64	54-72	60-80
Good passive solar house	3-4	6-8	9-12	12-16	15-20	18-24	21-28	24-32	27-36	30-40
Excellent passive solar house	1-2	2-4	3-6	4-8	5-10	6-12	7-14	8-16	9-18	10-20

DATA SHEET FOR SELECTED CITIES

		Solar Heating Fraction (SHF)								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Little Rock, AR	DG	269	140	84	53	33	19	---	---	---
3219 DD	DGNI	405	189	116	82	61	47	35	25	15
35° North Lat.	TW	232	112	67	44	30	21	14	9	---
	TWNI	356	165	103	73	54	40	30	22	14
	WW	239	108	66	46	33	24	17	11	---
	WWNI	365	172	107	76	57	44	35	26	18
Washington, DC	DG	226	115	67	40	23	---	---	---	---
4224 DD	DGNI	352	162	100	70	52	39	29	20	12
39° North Lat.	TW	180	85	50	32	21	13	8	---	---
	TWNI	285	131	81	57	41	31	22	16	10
	WW	179	79	47	32	22	15	9	---	---
	WWNI	292	135	83	58	44	33	25	18	12
Apalachicola, FL	DG	818	446	287	199	144	105	75	52	31
1308 DD	DGNI	1094	506	321	230	175	137	107	80	55
30° North Lat.	TW	635	313	194	133	95	70	51	36	24
	TWNI	906	240	266	189	142	108	82	61	42
	WW	700	322	204	145	110	85	65	48	32
	WWNI	956	444	281	203	155	123	97	75	53
Gainesville, FL	DG	858	467	301	210	152	111	81	56	34
1239 DD	DGNI	1146	524	335	241	184	145	113	84	58
30° North Lat.	TW	662	326	202	139	100	73	54	39	25
	TWNI	943	435	276	197	148	113	86	64	44
	WW	731	333	212	152	116	90	69	51	35
	WWNI	1000	457	292	211	162	129	102	79	56
Tallahassee, FL	DG	702	383	245	169	121	88	63	43	25
1485 DD	DGNI	952	439	276	199	151	119	92	69	47
30° North Lat.	TW	563	279	172	117	84	61	45	32	21
	TWNI	809	376	237	169	127	97	73	54	37
	WW	621	285	179	128	97	75	57	42	28
	WWNI	857	397	249	180	138	109	87	67	48
Tampa, FL	DG	1403	803	534	381	281	210	157	114	75
683 DD	DGNI	1743	871	570	416	322	256	201	153	107
28° North Lat.	TW	1059	548	351	245	179	134	100	73	49
	TWNI	1443	717	467	339	258	199	152	114	80
	WW	1147	573	374	272	210	166	129	98	69
	WWNI	1520	760	500	365	283	227	182	141	102

Solar Heating Fraction
(SHF)

		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Atlanta, GA	DG	342	180	110	72	48	31	18	---	---
2961 DD	DGNI	501	230	142	100	75	58	43	31	20
34° North Lat.	TW	286	138	55	38	27	18	12	7	---
	TWNI	431	198	123	87	64	48	36	26	17
	WW	301	136	83	58	43	31	23	15	8
	WWNI	448	207	129	91	69	54	42	32	22
Lexington, KY	DG	151	71	36	---	---	---	---	---	---
4683 DD	DGNI	261	119	72	50	36	27	19	12	---
38° North Lat.	TW	148	70	40	25	16	10	5	---	---
	TWNI	242	112	69	48	35	26	19	13	8
	WW	143	63	36	24	16	10	---	---	---
	WWNI	246	114	70	49	36	28	21	15	10
Lake Charles, LA	DG	601	325	208	143	102	73	51	34	18
1459 DD	DGNI	817	377	239	173	132	102	79	59	39
30° North Lat.	TW	481	237	146	100	71	52	38	26	17
	TWNI	695	322	204	146	109	83	63	46	32
	WW	522	239	152	109	82	63	48	35	23
	WWNI	730	338	214	155	119	94	74	57	40
Shreveport, LA	DG	406	218	137	92	64	44	29	17	---
2184 DD	DGNI	573	266	167	120	91	71	54	40	26
32° North Lat.	TW	340	167	103	69	49	35	25	17	10
	TWNI	500	234	148	105	79	60	45	33	22
	WW	361	166	104	74	65	42	31	22	14
	WWNI	524	245	154	111	85	67	53	40	28
Greensboro, NC	DG	264	137	82	52	33	19	---	---	---
3805 DD	DGNI	399	184	114	81	60	46	34	24	15
36° North Lat.	TW	231	112	67	44	30	21	14	9	---
	TWNI	354	165	103	72	54	40	30	22	14
	WW	237	107	66	46	33	24	17	11	---
	WWNI	367	170	107	75	57	44	35	26	18
Hatteras, NC	DG	463	249	156	105	73	50	34	20	---
2612 DD	DGNI	652	302	190	134	101	78	59	43	28
35° North Lat.	TW	381	187	115	77	54	39	28	19	11
	TWNI	560	261	164	115	86	65	49	36	24
	WW	412	189	118	82	61	46	34	24	15
	WWNI	588	274	173	123	93	73	57	43	30

Solar Heating Fraction
(SHF)

		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Raleigh, NC	DG	291	152	92	59	38	24	12	--	--
3393 DD	DGNI	432	200	124	87	66	51	38	27	17
36° North Lat.	TW	249	120	72	48	33	23	16	10	5
	TWNT	378	175	109	77	57	43	32	23	15
	WW	256	117	71	50	37	27	19	12	7
	WWNI	391	182	114	80	61	48	37	28	19
Oklahoma City,OK	DG	276	144	87	56	36	21	--	--	--
3725 DD	DGNI	412	192	119	84	63	48	36	26	16
35° North Lat.	TW	243	118	71	47	32	23	15	10	5
	TWNI	370	172	108	76	57	43	32	23	15
	WW	250	115	70	49	36	26	19	12	6
	WWNI	382	179	112	80	60	47	37	28	19
Charleston,SC	DG	507	276	174	118	83	58	40	25	--
2033 DD	DGNI	703	329	205	147	111	87	67	49	33
33° North Lat.	TW	407	202	124	84	59	43	31	21	13
	TWNI	594	279	176	124	93	71	53	39	27
	WW	442	204	127	90	67	52	39	28	18
	WWNI	624	295	184	132	100	79	63	48	34
Nashville, TN	DG	244	122	71	43	25	--	--	--	--
3578 DD	DGNI	384	172	104	72	53	40	30	20	12
36° North Lat.	TW	219	103	61	39	26	18	11	7	--
	TWNI	343	155	95	66	48	36	27	19	12
	WW	227	99	59	40	26	20	13	8	--
	WWNI	355	161	98	68	51	39	30	23	15
Oak Ridge, TN	DG	222	111	64	38	20	--	--	--	--
3817 DD	DGNI	352	160	97	68	50	38	28	19	11
36° North Lat.	TW	201	95	56	36	24	16	6	--	--
	TWNI	315	145	89	62	46	34	25	18	11
	WW	204	90	54	36	26	18	12	6	--
	WWNI	325	149	92	64	48	37	29	21	14
Brownsville, TX	DG	1309	741	493	351	258	192	142	101	65
600 DD	DGNI	1607	804	533	390	300	235	183	138	95
26° North Lat.	TW	976	506	324	226	165	123	91	66	44
	TWNI	1330	664	435	315	238	183	140	104	71
	WW	1052	526	348	254	194	151	117	88	60
	WWNI	1399	700	465	342	265	209	165	127	90

Solar Heating Fraction
(SHF)

		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
El Paso, TX	DG	506	278	177	121	85	60	41	26	--
2700 DD	DGNI	688	331	209	150	114	88	68	50	33
32° North Lat.	TW	402	202	125	85	60	44	31	22	13
	TWNI	582	279	178	126	94	72	54	40	27
	WW	431	205	129	92	69	52	39	28	18
	WWNI	608	295	187	134	103	80	63	48	34
Fort Worth, TX	DG	424	231	146	98	68	47	31	19	--
2405 DD	DGNI	590	280	177	127	96	75	57	42	27
33° North Lat.	TW	344	171	106	71	50	36	26	18	10
	TWNI	503	239	152	108	81	61	46	34	23
	WW	364	171	108	76	57	43	32	23	14
	WWNI	526	251	159	115	87	69	54	41	29
Midland, TX	DG	449	246	156	106	74	51	35	21	--
2591 DD	DGNI	616	298	188	134	102	79	61	45	29
32° North Lat.	TW	362	182	113	76	54	39	28	19	12
	TWNI	527	253	161	115	86	65	49	36	24
	WW	385	184	115	82	61	47	35	25	16
	WWNI	548	267	169	121	93	73	57	44	31
San Antonio, TX	DG	644	351	224	155	110	79	56	38	21
1546 DD	DGNI	873	406	256	184	140	110	85	63	43
30° North Lat.	TW	501	248	154	104	75	54	40	28	18
	TWNI	722	337	213	152	114	87	66	49	33
	WW	547	253	159	114	86	66	50	37	24
	WWNI	762	255	224	162	124	98	78	60	42

EXAMPLE PROBLEM

WORKSHEET FOR ESTIMATING PASSIVE SOLAR PERFORMANCE

A 72'×24' RANCH HOME IN ATLANTA WITH 309 SF OF WATER WALL WITH NIGHT INSULATION ON THE SOUTH FACADE. AN OIL BURNING FURNACE WILL PROVIDE THE AUXILLIARY HEAT REQUIRED.

1) Building Skin Conductance

Surface Type	Area		"U"		A x U
WATER WALL	309	x		=	NOT INCLUDED
OTHER WALL	1,107	x	0.07	=	77.5
WINDOWS	120	x	0.55	=	66.0
ROOF	1,728	x	0.05	=	86.4
FLOOR	1,728	x	0.05	=	86.4
		x		=	
		x		=	

Building Skin Conductance = 316.3 BTU/°F/HR

2) Infiltration Loss

Interior Volume × Air Change

12,320 cf × 0.5 × 0.018 = 110.9 (BTU/°F/HR)

3) Building Loss Coefficient (add #1 plus #2)=

427.2 BTU/°F/HR

× 24 HR

10,253 BTU/DD

4) Load Collector Ratio

$$\frac{\text{Building Loss Coefficient}}{\text{Solar Collector Area}} = \frac{10{,}253}{309}\ \frac{\text{BTU/DD}}{\text{SF}}$$

= 33.2 BTU/DD/SF

5) Load Collector Ratio (LCR) 33.2 BTU/DD/SF

First Table Number	42	First Table Number	42.0
Second Table Number	- 32	Calculated LCR	- 33.2
difference # 1	10	difference # 2	8.8

$$\frac{\text{difference \# 2}}{\text{difference \# 1}} = \text{interval ratio}$$

$$\frac{8.8}{10} = .88$$

SHF for first table number	0.7
SHF for second table number	- 0.8
difference # 3	0.1

difference #3 x interval ratio = SHF interval
+ SHF for first table number
final SHF

.88 x 0.1 = 0.088
+ 0.7
final SHF = 0.788

6) Annual Heating Load (AHL)

(1-SHF) X BLC X DD = AHL

.212 x 10.253 x 2961 = 6,436,136 BTU/YR

7) Annual Energy Use Index (AEUI)

$$\frac{\text{AHL}}{\text{FA}} = \text{AEUI}$$

$$\frac{6{,}436{,}136}{1{,}728} \ \frac{\text{BTU/YR}}{\text{SF}} = 3{,}725 \text{ BTU/SF/YR}$$

8) Energy Budget (EB)

$$\frac{\text{AEUI}}{\text{Eff}} = \text{EB}$$

$$\frac{3{,}725 \text{ BTU/SF/YR}}{0.6} = 6{,}208 \text{ BTU/SF/YR}$$

9) Annual Fuel Requirement (AFR)

$$\frac{\text{AHL}}{\text{Eff x CF}} = \text{AFR}$$

$$\frac{6{,}436{,}136 \text{ BTU/SF/YR}}{0.6 \text{ X } 138{,}000 \text{ BTU/gal.}} = 78 \text{ gal. of oil}$$

$$\frac{\text{BTU/SF/YR}}{\text{X } 1{,}000 \text{ BTU/CF}} = \_\_\_\_\_\_\_\_ \text{ CF of gas}$$

$$\frac{\text{BTU/SF/YR}}{\text{X } 3{,}413 \text{ BTU/KWH}} = \_\_\_\_\_\_\_\_ \text{ KWH of elect.}$$

WORKSHEET FOR ESTIMATING PASSIVE SOLAR PERFORMANCE

1) **Building Skin Conductance**

Surface Type	Area		"U"		A x U
		x		=	
		x		=	
		x		=	
		x		=	
		x		=	
		x		=	
		x		=	

Building Skin Conductance = ________ BTU/°F/HR

2) **Infiltration Loss**

Interior Volume　Air Change

______________ x ______________ x 0.018 = ________ (BTU/°F/HR)

3) **Building Loss Coefficient** (add #1 plus #2)=

______________________ BTU/°F/HR

______________ x 24 HR

______________________ BTU/DD

4) **Load Collector Ratio**

$$\frac{\text{Building Loss Coefficient}}{\text{Solar Collector Area}} = \frac{\text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_ BTU/DD}}{\text{SF}}$$

= ______________________ BTU/DD/SF

5) Load Collector Ratio (LCR) ____________________ BTU/DD/SF

First Table Number ________ First Table Number __________
Second Table Number - ________ Calculated LCR - __________
difference # 1 ________ difference # 2 __________

$$\frac{\text{difference \# 2}}{\text{difference \# 1}} = \text{interval ratio}$$

______________ = ____________

SHF for first table number __________
SHF for second table number __________
difference # 3 __________

difference #3 x interval ratio = SHF interval
+ SHF for first table number
final SHF

____________ x ______________ = ________________
+ ______________
final SHF = ________________

6) Annual Heating Load (AHL)

(1-SHF) X BLC X DD = AHL

___________ x ___________ x __________ = _________________BTU/YR

7) Annual Energy Use Index (AEUI)

$$\frac{AHL}{FA} = AEUI$$

______________ $\frac{\text{BTU/YR}}{\text{SF}}$ = ________________ BTU/SF/YR

8) Energy Budget (EB)

$$\frac{\text{AEUI}}{\text{Eff}} = \text{EB}$$

$$\underline{\qquad\qquad\qquad\qquad \text{BTU/SF/YR}} \quad = \quad \underline{\qquad\qquad\qquad\qquad\qquad \text{BTU/SF/YR}}$$

9) Annual Fuel Requirement (AFR)

$$\frac{\text{AHL}}{\text{Eff x CF}} = \text{AFR}$$

$$\frac{\underline{\qquad\qquad\qquad} \text{ BTU/SF/YR}}{\text{X } 138{,}000 \text{ BTU/gal.}} = \underline{\qquad\qquad\qquad\qquad} \text{ gal. of oil}$$

$$\frac{\underline{\qquad\qquad\qquad} \text{ BTU/SF/YR}}{\text{X } 1{,}000 \text{ BTU/CF}} = \underline{\qquad\qquad\qquad\qquad} \text{ CF of gas}$$

$$\frac{\underline{\qquad\qquad\qquad} \text{ BTU/SF/YR}}{\text{X } 3{,}413 \text{ BTU/KWH}} = \underline{\qquad\qquad\qquad\qquad} \text{ KWH of elect}$$

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ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

PASSIVE SOLAR DESIGN APPROACHES

STUDENT MATERIAL

ENERGY CONSERVATION AND PASSIVE DESIGN CONCEPTS

PASSIVE SOLAR DESIGN APPROACHES

INTRODUCTION

With increasing numbers of successful applications, passive techniques are being recognized as possibly the most efficient ways of using solar energy. Passive solar systems utilize architectural elements to collect, store and distribute energy rather than the mechanical means of active systems. Very often building components serve two purposes - structural and thermal.

The basic approaches which can be used either alone or in combination to form a passive solar system are:

1) Direct Gain - A very simple and frequently used system requiring only large south-facing windows and some sort of thermal storage mass in the living space.

   Sunlight enters the living space, strikes the thermal mass, and the solar energy is converted into heat, much of which is absorbed by the mass.

   When temperatures begin to drop, thermal energy stored in the mass begins to radiate into the space. Movable insulation covering the window at night will reduce heat losses to the outside. (See Figure 7-1, which is shown on the following page).

2) Thermal Storage Wall - The thermal storage in this system is directly behind the glazing. It can be either masonry (e. g., Trombe wall) or water (e.g., drum wall).

   The sun strikes the thermal mass and is converted into thermal energy. When temperatures drop, that energy travels through the mass carrying heat into the living space by radiation and natural convection (see Figure 7-2, which is shown on the following page).

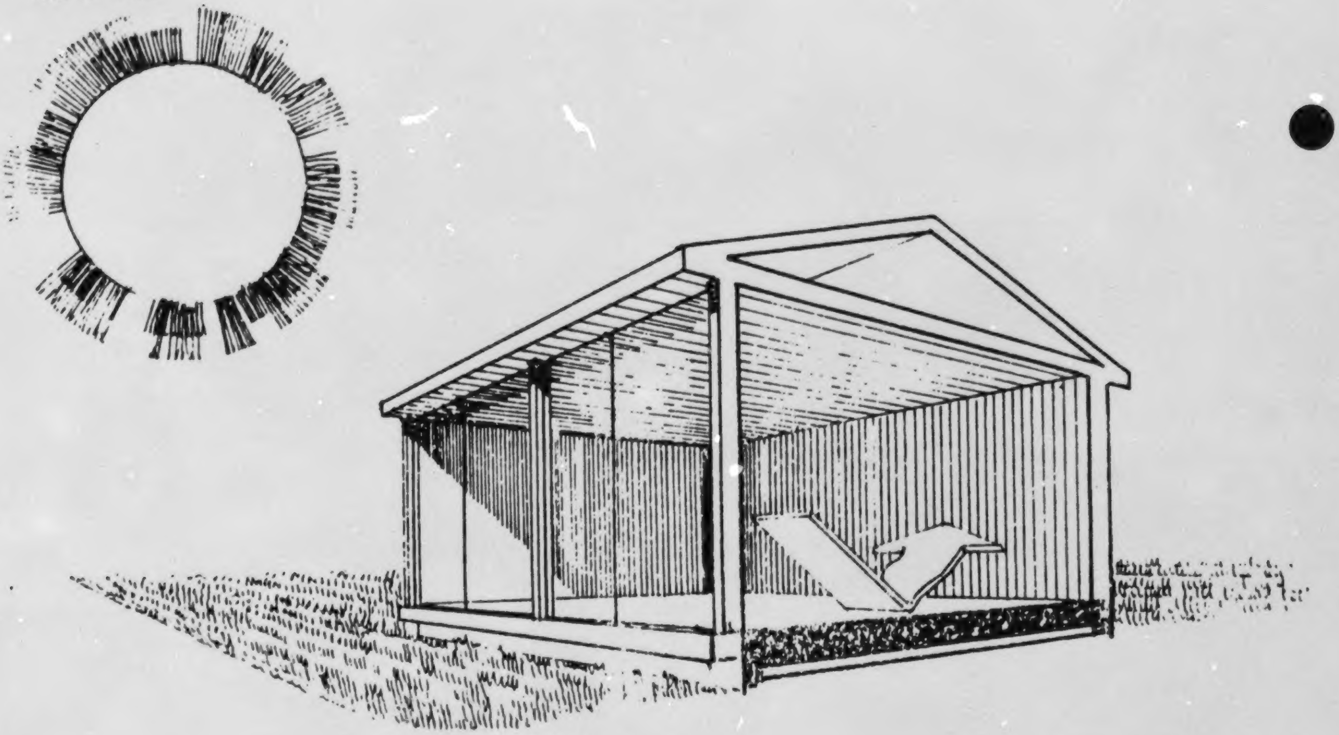
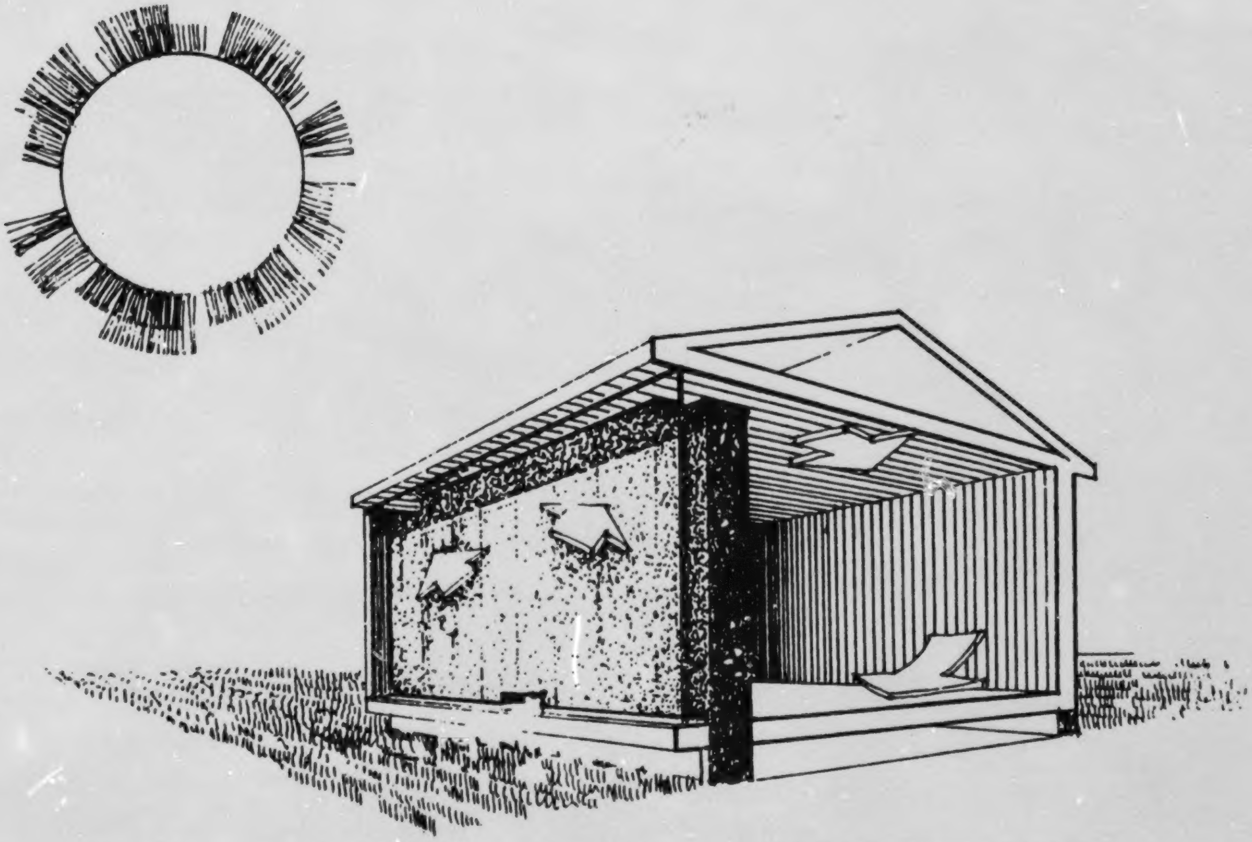


Figure 7-1



3) Attached Sunspace - This system operates essentially in the same manner as the thermal storage wall, except that the space between the glazing and the thermal wall is much larger and can be used. This technique is often referred to as "greenhouse" or "solar greenhouse". (See Figure 7-3).

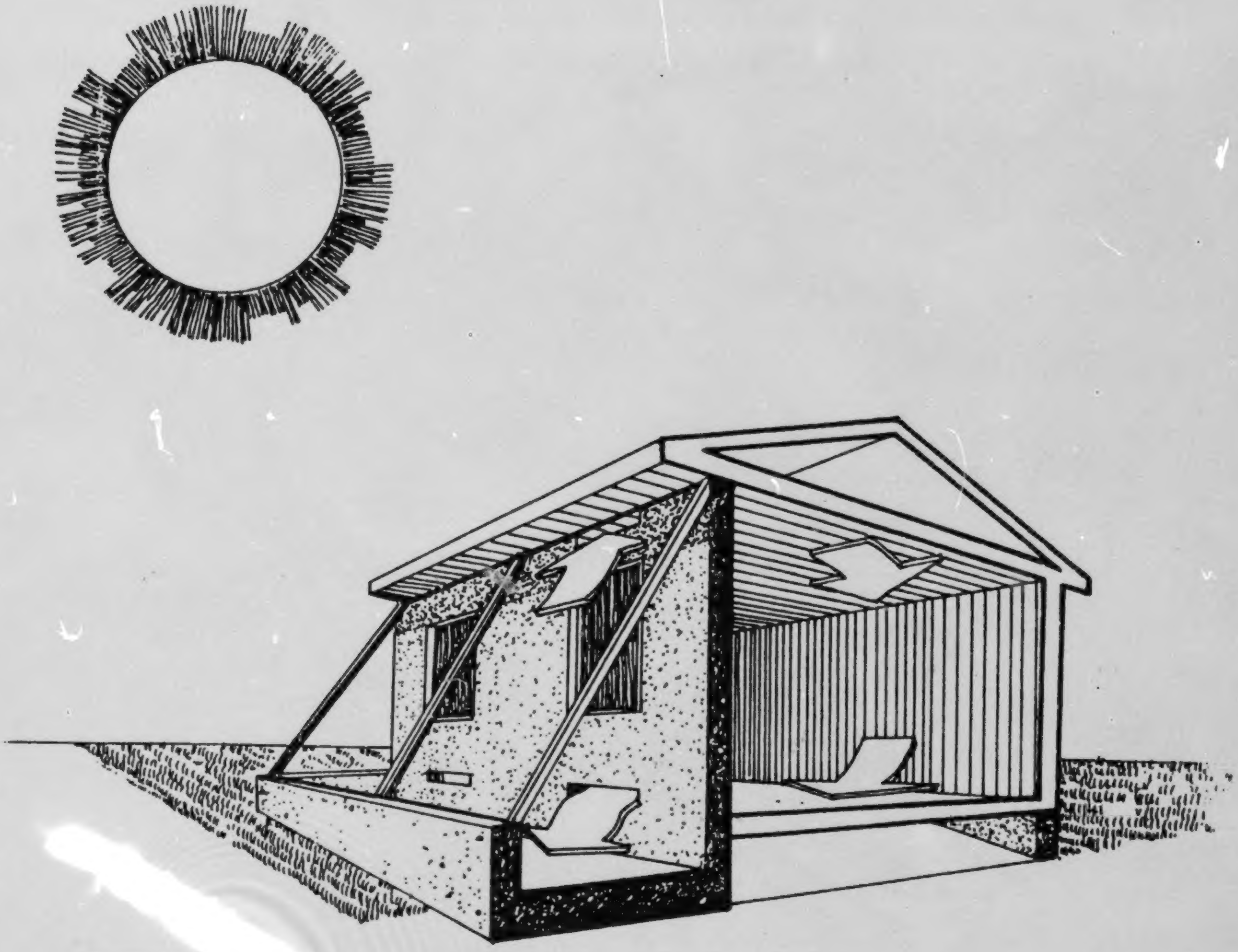


Figure 7-3

4) Thermal Storage Roof - In this system, the thermal mass is located on the roof, but essentially the process is the same.

During the sunlight hours the mass on the roof (usually water) collects the thermal energy and stores it as heat.

At night insulation is placed over the thermal mass, and the stored energy radiates into the space below.

This system can be reversed to provide cooling in the summer, by simply covering the mass during the day and exposing it at night (see Fig. 7-4).

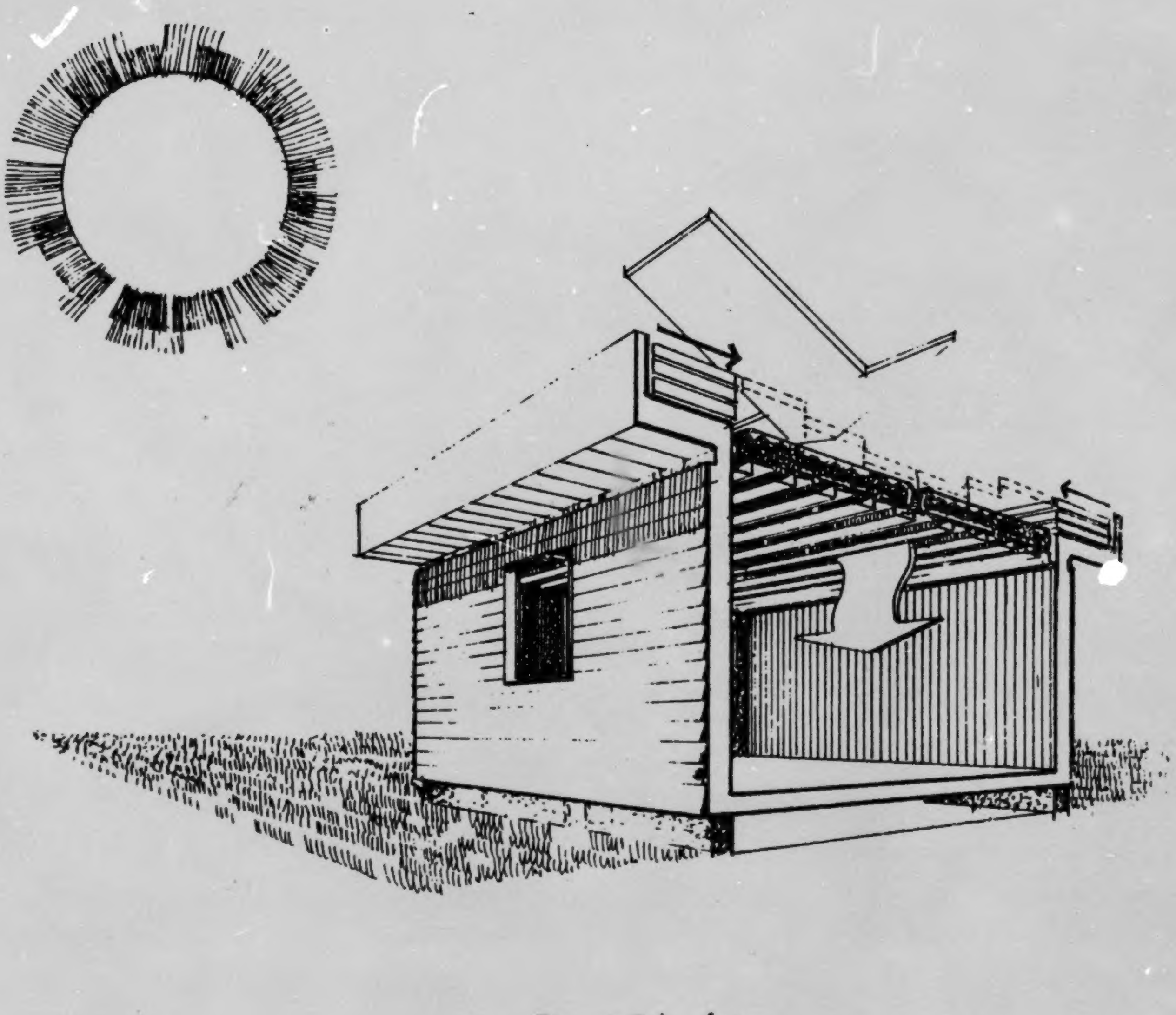


Figure 7-4

5) Convective Loop - In this system, the collector and thermal storage are separate units connected by piping or ducting. Circulation of a transfer medium (e. g., air) is by means of natural thermosiphon.

The sun striking the collector heats the transfer medium, which begins circulating through the loop by the natural convective process.

The thermal storage is heated by the transfer medium as it circulates through the loop. (See Figure 7-5).

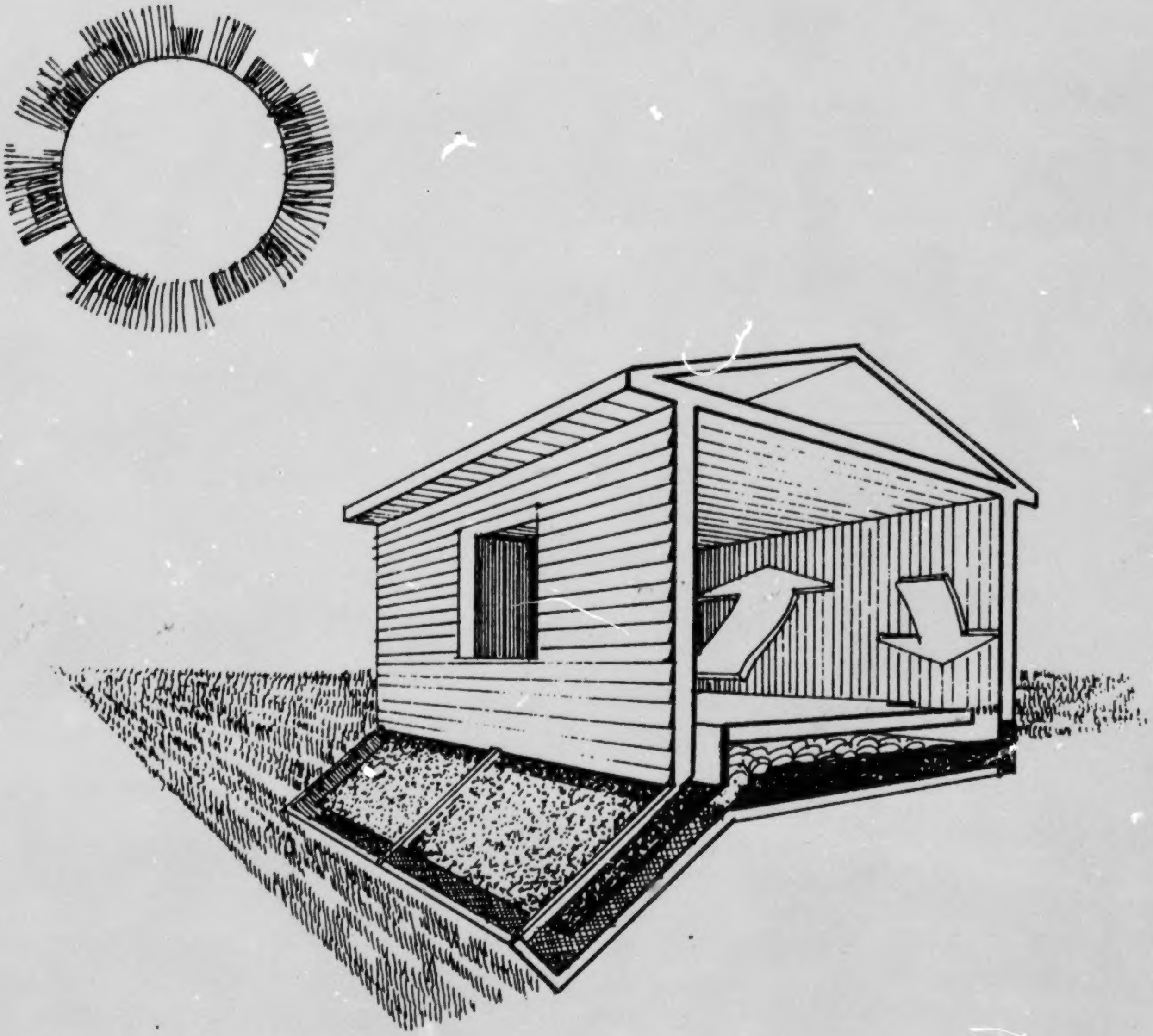


Figure 7-5

The basic approaches are utilized to provide passive solar systems according to five principal categories, or concepts, based on the approach or combination of approaches used to collect, store, and transmit thermal energy:

1. Direct gain approach - utilizes south wall windows, skylights, clerestory and sawtooth windows; shading overhangs for summer; internal mass for heat storage.
2. Indirect gain approach - utilizes thermal storage walls and roofs to intercept the sun and then transmits the heat to the space to be conditioned.
3. Attached sunspace - usually utilized in connection with indirect gain categories.
4. Isolated gain approach - indirect gain situations in which there is a major separation (by either distance or insulation) between thermal storage and conditioned space; natural convective loops.
5. Hybrid or Integrated approach - where several approaches are combined; may include active solar components as well as nonsolar components.

DIRECT GAIN APPROACHES

Definition

The Direct Gain concept is the most common passive solar building solution and has many historic precedents. Simply diagrammed as sun to living space to storage mass, the solar radiation is collected in the living space and then stored in a thermal storage mass (see Fig. 7-6). Thus, the actual living space is directly heated by the sun and serves as a live-in collector.

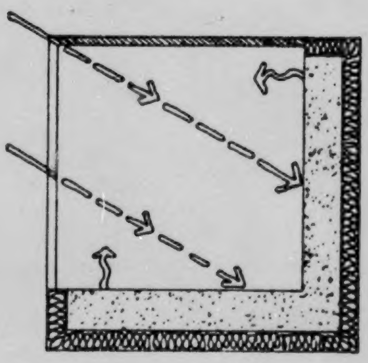


Fig. 7-6: Direct Gain

Requirements

The basic requirements for the Direct Gain building type are: a large south-facing glazed (collector) area, with the living space exposed directly behind; a floor and/or wall storage mass of significant dimensions for solar exposure and for capacity; and a method for isolating the storage from exterior climatic conditions. For the first requirement, a large expanse of collector glazing, often double glazing to minimize heat loss, is oriented facing due south to admit the maximum useful radiation, while facilitating the prevention of solar gain in summer.

Secondly, a considerable amount of thermal storage mass, in terms of walls, floors or free-standing mass, is incorporated in the building to store solar heat and provide longer term heating. The absence of thermal storage mass in most conventional homes is what eliminates the possibility of storing the heat gained through large expanses of picture windows.

Thirdly, the distribution of heat is controlled by the properties of the mass in relation to the space, and by insulation between the storage mass and the outdoors, or ground, which is critical in preventing unnecessary heat loss through temperate equalization.

Variations

Beyond these basic requirements, there are a series of variations and controls that demonstrate alternatives in passive solar heating by direct gain. The most common variations are found in the location and the materials of the thermal storage mass. The best location of the storage mass is often decided by the physical lows governing natural heat flow by radiation and convection. For effective radiant distribution, physical proximity to the radiant body is an important factor in the location of the storage. Where convective air movements are caused by warm air rising, different temperature stratifications may also exist in a room, depending on the location of the storage mass.

Typical location alternatives include: (a) the external building walls, (b) the internal walls, (c) the floor surface, and (d) free standing masses. In addition to storage location, there are significant variations in the storage materials, and the massing of those materials, which provide different heat capacities and different time lag properties. Storage materials vary from concrete, brick, sand, and ceramics, to water and other liquids, either singly or in various combinations, all radiating heat to the living space. The storage masses often incorporate circulation channels, plenums, or air spaces to improve the convective distribution of stored heat and provide a more sophisticated solar system with both radiant and convective heat contributions.

Controls

To add to the efficiency and the usefulness of direct gain and other passive systems, several controls must be considered. To prevent unwanted heat gain, sunshading is required for the large expanse of south facing glass. Due to the high location of the southern summer sun, overhangs can provide adequate protection for vertical southern glazing, but other solutions must be found for tilted glazing, or those with east and west orientations (faced with low sun angles). Exhausts and vents will also help cool interior spaces when summer temperatures are high.

To prevent unwanted heat loss, insulation for the glazed collector area is necessary to improve the low U-value (resistance to heat transfer) of glass. Movable insulation panels, curtains, shutters, Skylids, or Beadwall, all work effectively to prevent unwanted heat losses on sunless winter days and nights, and will also prevent thermal heat gain on hot summer days. Without these control considerations, the addition of a passive system with its large glazed exposure to the outside and adjacent masses with great heat storage potential can cause tremendous discomfort due to winter losses and summer overheating, and greatly decrease the potential effectiveness of passive solar buildings.

DIRECT GAIN SOLAR WINDOWS

Openings that are designed primarily to admit solar energy into a space are referred to as "solar windows". In a direct gain passive solar system, the most important factor in collecting the sun's energy is the size and placement of window openings. A window, skylight or clerestory that faces south and opens directly into a space is a very efficient solar collector. Lignt entering the space is unlikely to be reflected back out regardless of the color or shape of the space. This means that virtually all the sunlight is absorbed by the walls, floor, ceiling and other objects in the space and is converted into heat. Such windows can be oriented as much as 25° to the east or west of true south and still intercept over 90% of the solar radiation incident on a south-facing surface.

Solar Windows

The direct gain designs feature large south-facing windows, although windows facing toward the east or west may also be used if heat is desired earlier in the day or later in the afternoon. The windows are generally double glazed to reduce heat losses and improve net heat gain during the day. A single glazed window can result in net energy loss. It is desirable, and in severe climates, necessary, to insulate the windows at night using shutters or insulated curtains to reduce heat losses. Overhangs are desirable design features so that windows are shaded during the summer (see Figure 7-7).

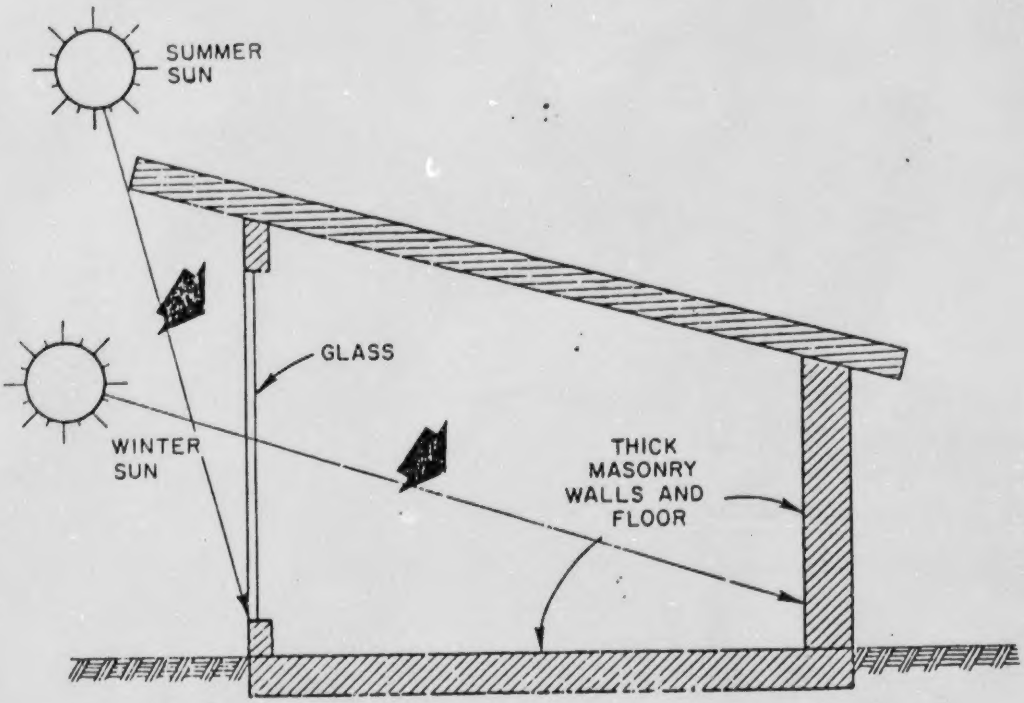


Figure 7-7

The size of a solar window determines the average temperature in a space over the day. During a typical sunny winter day, if a space becomes uncomfortably hot from too much sunlight, then the solar windows are either oversized or there is not enough thermal mass distributed within the space to absorb the incoming radiation properly. As a space becomes too warm, heated air is vented by opening windows or activating an exhaust fan to maintain comfort. This reduces the system's efficiency, since valuable heat is allowed to escape. For this reason, the criterion for a well-designed space is that it gain enough solar energy, on an average sunny day in December or January, to maintain an average space temperature of 70° F for that 24-hour period. Table 7-1 lists ratios for different climates that apply to a well-insulated residence.

TABLE 7-1.
SIZING SOLAR WINDOWS FOR DIFFERENT CLIMATIC CONDITIONS[1].

Average Winter Outdoor Temperature (°F) (degree-days/mo.)[2]	Square Feet of Window[3] Needed for Each One Square Foot of Floor Area
Cold Climates	
15° (1,500)	0.27–0.42 (w/night insulation over glass)
20° (1,350)	0.24–0.38 (w/night insulation over glass)
25° (1,200)	0.21–0.33
30° (1,050)	0.19–0.29
Temperate Climates	
35° (900)	0.16–0.25
40° (750)	0.13–0.21
45° (600)	0.11–0.17

NOTES: 1. These ratios apply to a residence with a space heat loss of 8 to 10 Btu/day-sq ft_{fl}-°F. If space heat loss is less, lower values can be used. These ratios can also be used for other building types having similar heating requirements. Adjustments should be made for additional heat gains from lights, people and appliances.

2. Temperatures and degree-days are listed for December and January, usually the coldest months.

3. Within each range, choose a ratio according to your latitude. For southern latitudes, i.e., 35°NL, use the lower window-to-floor-area ratios; for northern latitudes, i.e., 48°NL, use the higher ratios.

Recessing windows and using wood sash construction will further reduce heat loss. Single-glazing with wood frame construction transmits approximately 10% less heat than glazing with a metal assembly. As the glazing becomes more insulative (double or triple glazing), the type of framing becomes more significant. A double-glazed wood frame opening will transmit 20% less than a metal-framed opening. Only use metal sash that has a thermal break between the inside and outside face. At the outside surface of a window, wind will increase the infiltration of cold air into a building and will carry away heat at a faster rate than still air. Recessing windows back from the face of the exterior wall will decrease the movement of air against the window. However, when recessing windows, care should be taken on the south face to avoid excessive shading. Splaying the wall (Figure 7-8) will increase heat gain in winter.

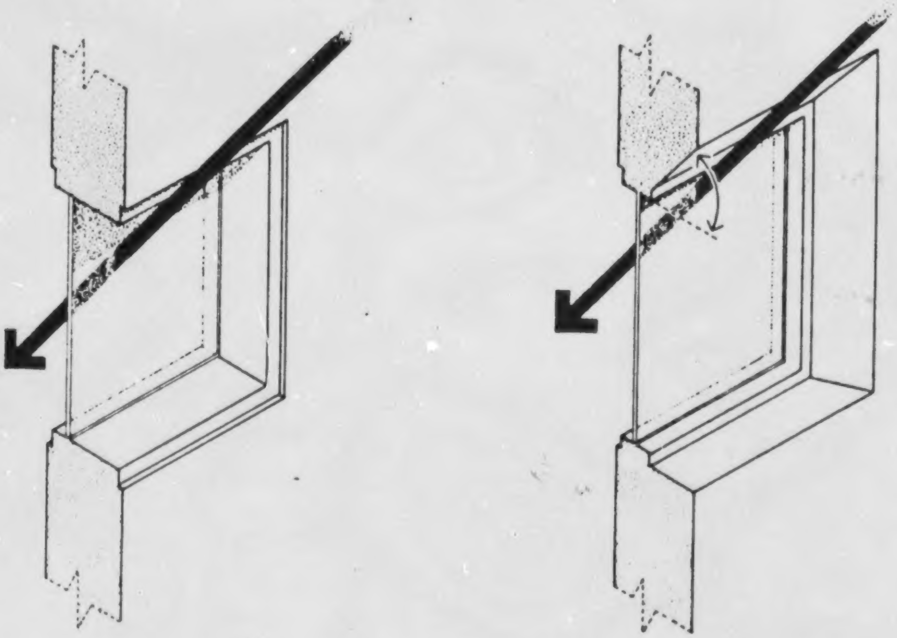


Figure 7-8: Splaying the wall will increase heat gain in winter.

Alternate Direct Gain Solar Windows

The exact location and size of window openings depends upon other design considerations such as special views, natural lighting and space use. There are many situations when admitting direct sunlight through south-facing windows is not feasible or desirable. Solar blockage of the south wall by nearby obstructions, or spaces without a clear southern exposure, make it impossible to use windows for solar gain. Also, the distance from a solar window to a thermal storage mass is limited by the height of the window. A mass located too far from the window will not receive and absorb direct sunlight. Large solar windows, which are the primary source of direct sunlight in a space, may result in troublesome glare, create uncomfortably warm and bright conditions for people occupying the space and discolor certain fabrics. For these and other reasons (privacy and aesthetics) it is necessary to explore alternative methods for collecting the sun's energy in a direct gain building.

Another method for admitting sunlight into a space is through the roof. Use either south-facing clerestories or akylights to distribute sunlight over a space or to direct it to a particular interior surface. Make the ceiling or the clerestory a light color and apply shading devices to both clerestories and skylights for summer sun control.

Collecting sunlight through south-facing clerestories and skylights has several advantages. Sunlight admitted through the roof can be distributed to any part of a space or building. This allows for maximum freedom when locating an interior thermal storage mass. When properly designed, toplighting eliminates the problem of glare since light entering the space from above reduces the contrast between interior surfaces and windows. Because clerestories and skylights are located high in a space, they reduce the chance of solar blockage by off-site obstructions and allow for large openings in crowded building situations where privacy is desirable.

Skylight (see Figure 7-9). There are two types of skylight configurations - horizontal and those located on a tilted roof. It is important when designing a horizontal skylight to use a reflector to increase solar gain in winter, since the amount of solar energy incident on a horizontal surface is considerably less than that incident on a south-facing vertical or sloping surface. Also, all skylights of any considerable size should have either interior or exterior shading devices to prevent excessive solar

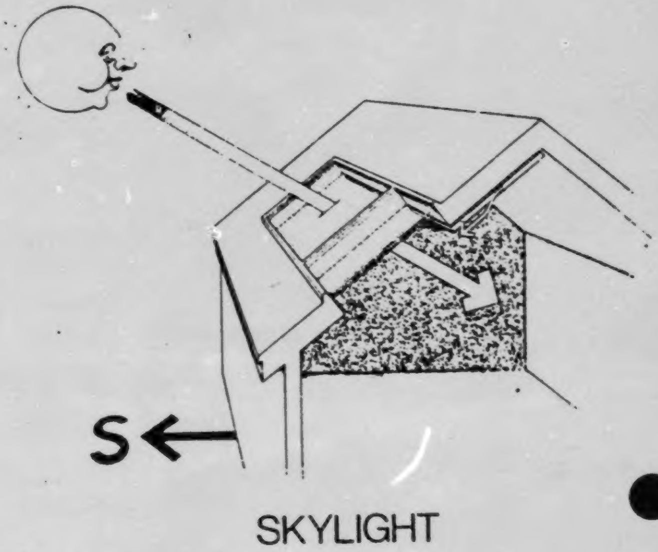


Figure 7.9

Clerestory: A clerestory (Figure 7-10) is a vertical or near vertical opening projecting up from the roof plane. It is a particularly effective way to direct sunlight entering a space so that it strikes an interior thermal storage wall.

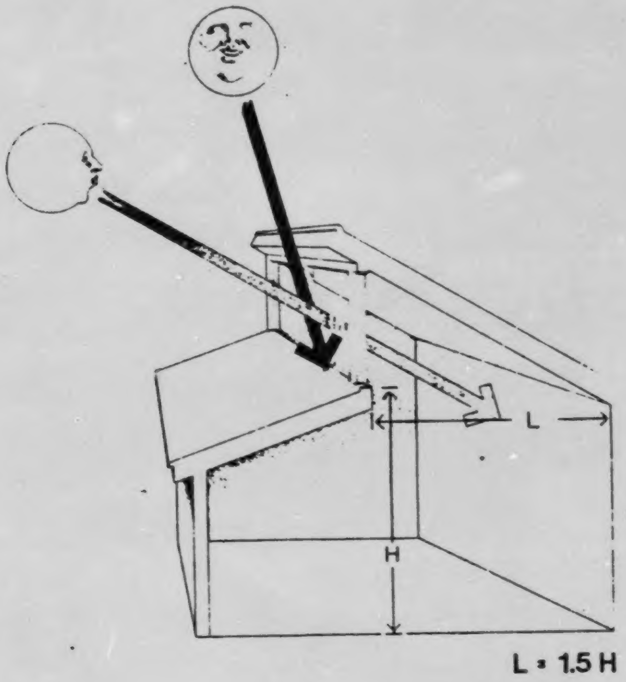
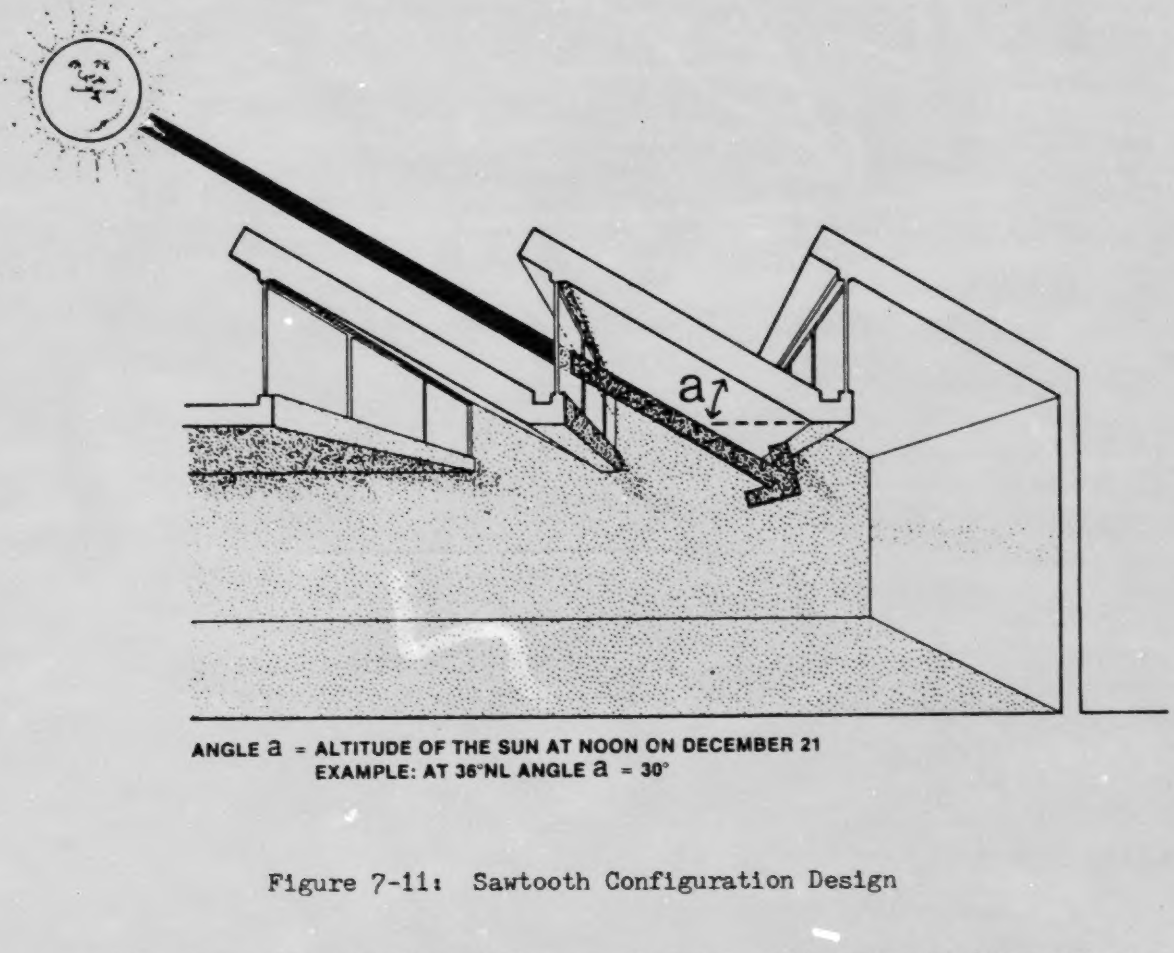


Figure 7-10: Clerestory Location.

Care must be exercised to locate the clerestory at a distance in front of the wall which insures that direct sunlight will strike most of the wall during the winter. This distance will vary with latitude and ceiling height but is roughly 1 to 1-1/2 times the height of the wall. The ceiling of the clerestory should be either a light color to reflect and diffuse sunlight down over the space, or a polished surface to direct the sunlight to a thermal wall. In summer shading the clerestory can be achieved by extending its roof to provide an overhang. The angle of the glass can be tilted to increase solar gain in winter, but tilting the glazing also increases solar gain in summer, making sun control devices essential. The exterior roof below a clerestory can be treated as a reflecting surface for maximum solar gain.

Sawtooth: The sawtooth (Figure 7-11) is a series of clerestories, one directly behind the other. When glazed with a translucent glazing material, the sawtooth effectively distributes sunlight over an entire space. As a rough guide, make the angle of each clerestory roof (as measured from horizontal) equal to, or less than, the altitude of the sun at noon, on December 21, the winter solstice. This assures that the clerestories will not shade each other during the winter hours of maximum solar radiation. If a steeper angle is used, then clerestories should be spaced apart accordingly.



ANGLE a = ALTITUDE OF THE SUN AT NOON ON DECEMBER 21
EXAMPLE: AT 36°NL ANGLE a = 30°

Figure 7-11: Sawtooth Configuration Design

DIRECT GAIN THERMAL STORAGE

The solar energy transmitted through the south glazing of a passive solar-heated building will greatly exceed the thermal losses on a clear winter day.

For example, if the total energy transmitted through 240 square feet of south glazing is approximately 1500 Btu per square foot on a clear winter day, then the total would be 360,000 Btu. By simply dividing this total energy transmission by the total thermal load of the building, the average 24-hour temperature difference, which can be maintained between the inside and outside temperatures, can be determined. For an effective conductance heat loss of 362 Btu/hr-$^\circ$F, this yields:

$$(360{,}000 \text{ Btu/day})/(24 \text{ hours/day})(362 \text{ Btu/hr-}^\circ\text{F}) = 41^\circ \text{ F.}$$

Thus, the inside temperature could be maintained at 70° F if the outside temperature averaged 28° F over the 24 hour period.

If it is assumed that the inside temperature is somewhat higher during the daytime, for example, 75° F, and the outside temperature is lower, say, 20° F, then the average energy lost by the house over the eight daytime hours can be calculated as follows:

$$(75^\circ \text{ F} - 20^\circ \text{ F})(362 \text{ Btu/hr-}^\circ\text{F})(8 \text{ hours/day}) = 160{,}000 \text{ Btu/day.}$$

Thus, less than half of the total energy collected during the day is lost during the same day. If a large and effective thermal storage mass is not included within the envelope of the building, it will simply overheat to the point where the energy losses balance the net incoming energy. The occupants would take remedial action by opening the windows or, if this were not done, temperatures well over 100° F could be anticipated.

In a properly designed passive solar-heated building, the 200,000 Btu/day of excess energy will be stored in the sensible heat of building materials. The mass of material required depends on a thermal storage capacity, or specific heat c_p, and on the temperature change of the material. Thus:

$$\text{Stored solar energy} = \sum M_s c_p \, \Delta t$$

where: M_s is the mass of storage material,

c_p is the specific heat of storage material,

Δt is the temperature swing of storage material.

In order for this heat to be stored in the thermal mass of the room, it must first be transferred to the surface of the mass element and then conducted into the interior of this element. The process at night is the reverse - conduction out of the element to the surface and then transmission back into the room by convection and radiation. Physical properties for some common masonry materials are given in Table 7-2.

TABLE 7-2.
THERMAL STORAGE MATERIAL PROPERTIES.

Material	Conductivity (k)	Specific Heat (Cp)	Density (ρ)
	Btu hr/ft^2-°F ft	Btu/lb-°F	lb/ft
Concrete (dense)	1.00	0.20	140.0
Brick (common)	0.42	0.20	120.0
Brick (magnesium additive)	2.20	0.20	120.0
Adobe	0.30	0.24	106.0

Types of Thermal Storage

The most effective heat storage is in walls or floors which are directly or indirectly illuminated by the sun. It is good design practice to make the massive storage walls a dark color and other materials in a sunny room light in color so that the sunlight is reflected and eventually absorbed in the storage walls. Interior walls which are not irradiated by direct or indirect sun can also store heat. Slightly oversize solar windows and thermal mass to collect and store heat for cloudy days. It is essential to insulate the exterior face of the mass to keep stored heat inside the space. Also, a thermal mass cooled during summer evenings will absorb heat and provide cool interior surfaces on hot days. When masonry construction is not possible, or desirable, an interior water wall can be used for heat storage.

Although heat storage in the floor is economical, it is relatively ineffective unless the floor is of masonry construction, is uninsulated on the surface, and is located in the direct (unshaded) sun. (This is a severe requirement, seldom met. People like to put rugs, furniture, potted plants, teddy bears and other things in their living space.) Thermal storage in side walls is also difficult because they are seldom located in the direct sun. Thus, extensive (and expensive) mass must be deployed. Thermal storage in the ceiling would be very effective because of the tendency of the heat to gravitate upwards toward it. This has not been used extensively, however. The phase change ceiling tiles being experimentally developed at MIT may be an advance in this direction.

Masonry Thermal Storage: In the process of storing and releasing heat, the masonry fluctuates in temperature, yet the object of the heating system is to maintain a relatively constant interior temperature. The location, quantity, distribution and surface color of the masonry in a space will determine the indoor temperature fluctuation over the day.

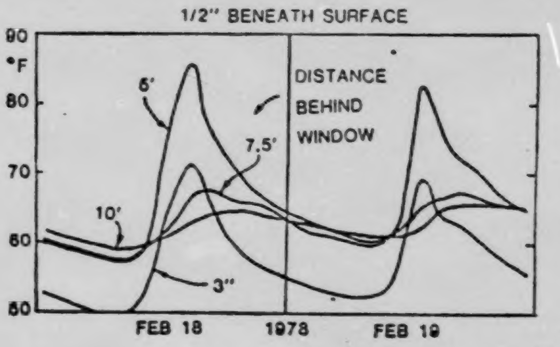
To minimize indoor temperature fluctuations, construct interior walls and floors of masonry with a minimum of 4 inches in thickness. Diffuse direct sunlight over the surface area of the masonry by using a translucent glazing material, by placing a number of small windows so that they admit sunlight in patches, or by reflecting direct sunlight off a light-colored interior surface first, thus diffusing it throughout the space. The following are guidelines for selecting interior surface colors and finishes:

1. Choose a dark color for masonry floors;
2. Masonry walls can be any color;
3. Paint all lightweight construction (little thermal mass) a light color;
4. Avoid direct sunlight on dark-colored masonry surfaces for long periods of time;
5. Do not use wall-to-wall carpeting over masonry floors.

When the entire interior of a space is constructed of masonry, then walls can be as thin as 3 to 4 inches without indoor fluctuations.

Results of analysis show that for a space to remain comfortable during the day, each square foot of direct sunlight must be diffused over at least 9 square feet of masonry surface. Masonry can be used to store heat, but even thick masonry cannot absorb and store enough heat when exposed to direct sunlight throughout the day. Most masonry materials transfer heat from their surface to the interior at a slow rate. If too much heat is applied, the surface layer of the material becomes uncomfortably hot, giving much of the heat to the air in the space rather than conducting it away from the surface for storage. By using masonry of higher conductivity, air temperature fluctuations in the space can be minimized. This is the result of a rapid transfer of heat away from the surface of a material to its interior, where it is stored for use during the evening.

Data are now being obtained on test rooms and on several direct gain passive structures. The plot in Figure 7-12 shows the temperature of the floor in a Santa Fe house which Los Alamos is monitoring.



Floor temperatures measured in a direct gain house along a line extending north from the windows. The shadow line is about 5'9". The measurement at 3" is low due to cold air falling down the window.

Figure 7-12: Direct Gain Brick Floor

Interior Water Wall: A portion of the sunlight (heat) admitted into each space can be stored in a water wall for use during the evening hours (see Figure 7-13 on the following page). The size of a water wall and its surface color determine the temperature fluctuations in a space over the day. Solar windows are sized to admit enough sunlight to keep a space at an average temperature of 65° to 70° F during most of the winter. The volume of water in the space and the surface color of the container will influence the indoor

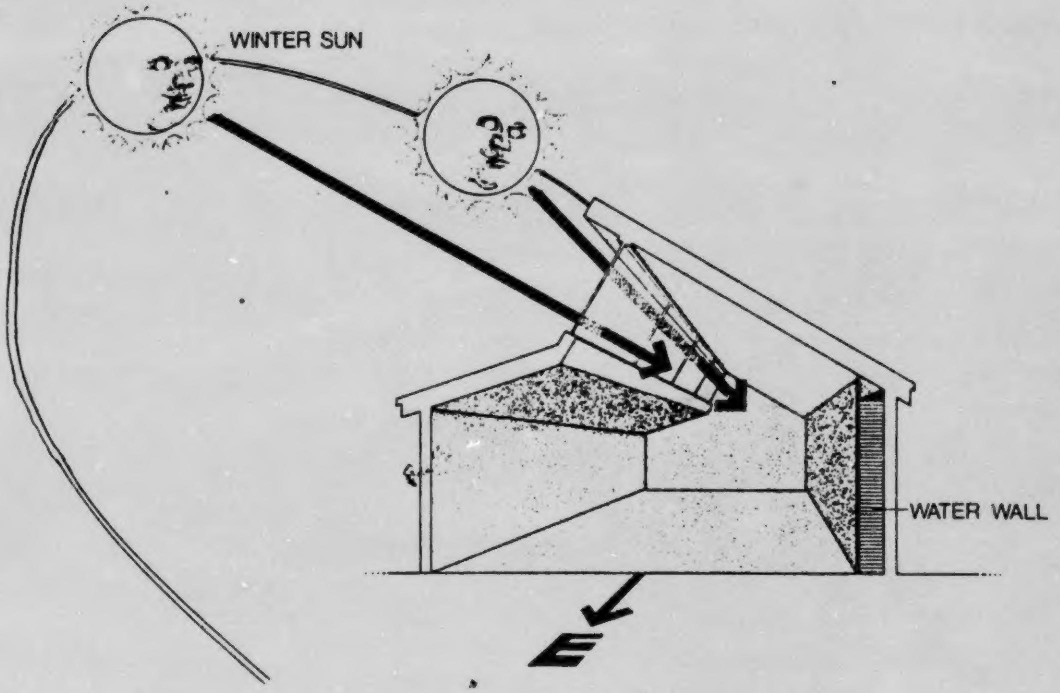


Figure 7-13

temperature fluctuation above and below this average. The size of the water wall needed to maintain a comfortable environment is directly related to the area of the solar windows.

Masonry may need sunlight diffused over a large surface area, but water in containers can absorb heat effectively even when it's concentrated by a reflector. There are two reasons for this.

First, water is a more efficient storage medium than masonry. A cubic foot of water will store 62.4 Btu's for each 1° F temperature rise, while the same volume of concrete stores only 28 Btu's for each 1° F rise in temperature.

Second, a water wall heats up uniformly, using all its mass for storage, while masonry passes heat slowly from its surface to its interior (see Figure 7-14). When a dark-colored masonry wall is exposed to direct sunlight, the surface temperature rises rapidly while its interior remains cool. Since masonry conducts heat slowly, only a small portion of the wall stores heat. It will take approximately 5 hours for heat to pass through an 8-inch concrete wall.

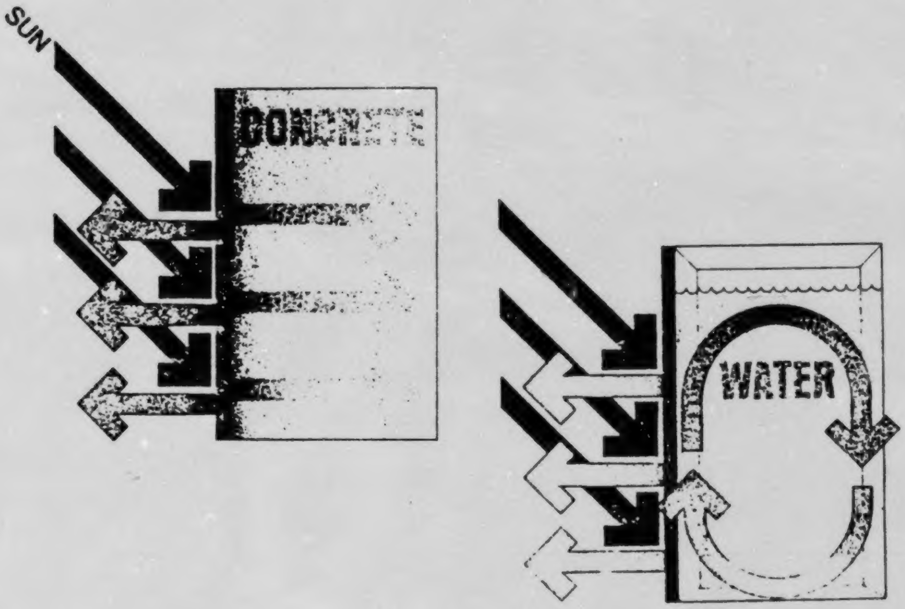


Figure 7-14: Heat Transfer in a Concrete and Water Storage Mass.

In contrast, a water wall transfers heat rapidly from the collecting surfact to the entire volume of water. As sunlight heats the surface of the container, water in contact with the inside face is heated, becomes less dense, and rises. This movement of water produces a convection current, which distributes the heat throughout the container. By using all its mass for heat storage, the surface temperature of a water wall rises very slowly when compared to a masonry wall.

The volume of water in direct sunlight is the major determinant of temperature fluctuation in a space over the day. To illustrate this, an interior water wall was analyzed by computer for different quantities of water (wall thickness) using January clear-day, solar radiation and weather data for New York City. The results are shown in Figure 7-15. Note that space air temperature fluctuations decrease as the volume of the wall increases. The space with 1 cubic foot of water for each 1 square foot of glass has a temperature fluctuation of 17° F, while the same space with 3 cubic feet of water for 1 square foot of glass fluctuates only 12° F.

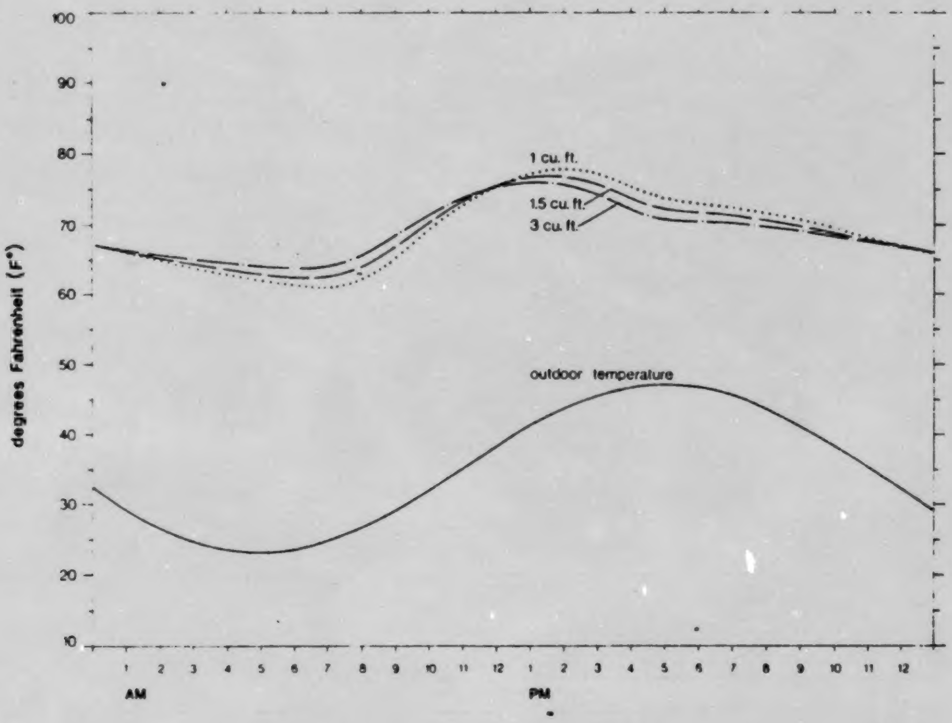


Figure 7-15: Indoor Temperatures Using Various Water Walls.

Note: Clear-day indoor air temperatures are for a well-insulated space with 0.25 square feet of south-facing glass for each one square foot of building floor area, i.e., a 200-square foot space would have 50 square feet of south-facing glass.

Table 7-3, shown on the following page, lists the approximate air temperature fluctuations that can be expected in a space with various quantities of water and south-facing glass. The table also illustrates winter clear-day space temperature fluctuations for a water wall as a function of surface color. When thermal storage materials are concentrated in a small area, such as a water wall in a wood frame building, it is important to absorb and store as

TABLE 7-3
DAILY SPACE AIR TEMPERATURE (°F) FLUCTUATIONS[1] FOR WATER STORAGE WALL SYSTEMS

Solar Absorption[2] (surface color)	Volume[3] of Water Wall for Each One Square Foot of South-Facing Glass			
	1 cu ft	1.5 cu ft	2 cu ft	3 cu ft
75% (dark color)	~17°	~15°	~13°	~12°
90% (black)	15°	12°	10°	9°

NOTES: 1. Temperature fluctuations are for a winter-clear day with approximately 3 square feet of exposed wall area for each one square foot of glass. If less wall area is exposed to the space, temperature fluctuations will be slightly higher. If additional mass is located in the space, such as masonry walls and/or floor, then fluctuations will be less than those listed.

2. Assumes 75% of the sunlight entering the space strikes the mass wall.

3. One cubic foot of water = 62.4 pounds or 7.48 gallons.

much direct sunlight in the mass as possible. The greater the absorption of sunlight, the smaller the daily temperature fluctuation in the space. It is estimated that if the wall is not exposed to direct sunlight, roughly 4 times the amount of storage is needed.

Sizing the Thermal Storage

The size or surface area of a thermal storage wall is dependent upon three factors: the local climate, latitude, and space heat loss. Each factor influences the size of a wall in the following way:

Climate: The rate of heat loss from a space is largely determined by the difference between indoor and outdoor air temperatures. The larger this difference, the faster the rate of building heat loss. Therefore, in cold climates, more heat or a larger thermal storage wall is needed to keep a space at 70° F.

Latitude: Solar energy incident on a south-facing wall during the winter changes as the location or latitude of the building changes. As a general rule, a thermal storage wall system will increase in size, the farther north a building is located.

Space Heating Requirements: A well-insulated and tightly sealed space requires less heat to keep it at a specified temperature, and, therefore, requires less wall.

Sizing the System: The criterion for a well-designed thermal storage wall is that it transmit enough thermal energy (heat), on an average sunny day in January, to supply a space with all its heating needs for that day. This means that the energy transmitted through the wall will be sufficient to maintain an average space temperature of 65° to 75° F over the 24-hour period. Ratios, based on this criterion, for the amount of double-glazed, south-facing thermal storage wall needed for each square foot of space floor area, and for different climates are given in Table 7-4. These ratios apply to a well-insulated residence with a space heat loss between 7 and 9 Btu/day-sq.ft.-°F (assuming no heat loss through the thermal wall).

TABLE 7-4.
SIZING A THERMAL STORAGE WALL FOR
DIFFERENT CLIMATIC CONDITIONS.

Average Winter Outdoor Temperature (°F) (degree-days/mo.)[1]	Square Feet of Wall[2] Needed for Each One Square Foot of Floor Area	
	Masonry Wall	Water Wall
Cold Climates		
15° (1,500)	0.72–>1.0	0.55–1.0
20° (1,350)	0.60–1.0	0.45–0.85
25° (1,200)	0.51–0.93	0.38–0.70
30° (1,050)	0.43–0.78	0.31–0.55
Temperate Climates		
35° (900)	0.35–0.60	0.25–0.43
40° (750)	0.28–0.46	0.20–0.34
45° (600)	0.22–0.35	0.16–0.25

NOTES: 1. Temperatures and degree-days are listed for December and January, usually the coldest months.

2. Within each range choose a ratio according to your latitude. For southern latitudes, i.e., 35°NL, use the lower wall-to-floor-area ratios; for northern latitudes, i.e., 48°NL, use the higher ratios. For a poorly insulated building always use a higher value. For thermal walls with a horizontal specular reflector equal to the height of the wall in length, use 67% of recommended ratios. For thermal walls with night insulation (R-8), use 85% of recommended ratios. For thermal walls with both reflectors and night insulation, use 57% of recommended ratios.

A thermal storage wall system will perform effectively if either more or less than the recommended wall areas are used. The exact size of the wall depends on many considerations such as views, natural lighting, solar blockage and cost. Because of these and other considerations, it may be desirable to use a different wall size that is recommended here.

DIRECT GAIN APPLICATIONS

Solar Windows

One of the earliest and largest contemporary examples of a direct gain system is the St. George's Secondary School in Wallasey, England, near Liverpool. Wallasey is located on the west coast of England at 53° N latitude. The building was completed in 1962, but it was not until the late 1960's that extensive research and testing of the building was begun.

The building, shown schematically in Figure 7-16, is constructed of masonry,

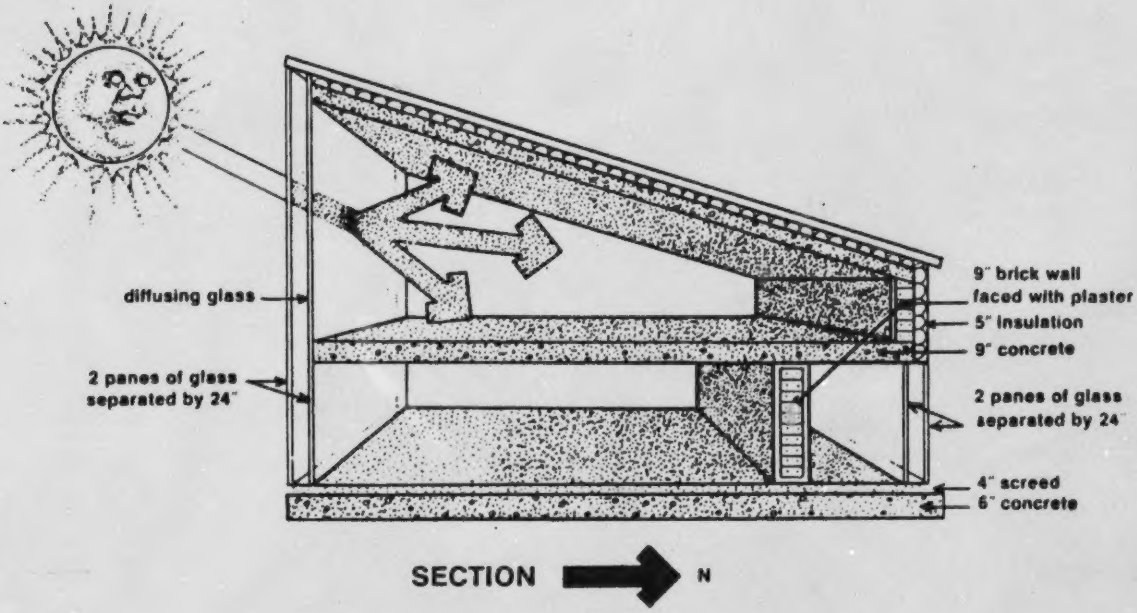

diffusing glass
2 panes of glass separated by 24"
9" brick wall faced with plaster
5" insulation
9" concrete
2 panes of glass separated by 24"
4" screed
6" concrete
SECTION
N

Figure 7-16: Sunlight is diffused over a large surface area of masonry.

and has a transparent south wall for maximum solar gain in winter. Concrete, 7 to 10 inches in thickness, forms the roof and floors, with the north wall and interior partitions made of 9-inch brick. This masonry is the principal means of heat storage in the building. It is exposed to the interior and insulated from the exterior with 5-inches of expanded polystyrene. By contrast, the entire south wall of the building is essentially transparent. Two sheets of glass, the outside layer clear and the inside translucent, make up the roughly 230-by-27 foot wall. The translucent layer refracts direct sunlight, diffusing it over the surface area of interior mass, somewhat uniformly.

The masonry interior stores heat and acts to prevent large fluctuations of indoor temperatures over the day. Recorded classroom fluctuations are on the average only 7° F throughout the year (clear-day fluctuations are somewhat higher). A conventional heating system, originally installed, was never used and was subsequently removed. Temperature control is accomplished by means of:

1. Lights, which are left on up to 24 hours a day in the winter, and as little as possible in the summer.

2. Ventilation, which is relied on entirely for summer cooling. It is successful in the art room. Corridor noise keeps the staff from opening the classroom vents, with consequent occasional overheating. During one hot period, classes were held outdoors.

3. Choice of clothing, which has become automatic and is no problem.

A data-collection system installed in 1969 ran continuously for 19 months, recording indoor and outdoor temperatures, wall temperatures, and the insolation of the south wall. Qualitatively, some of the results are:

1. The solar wall showed net heat losses during December, January, February, and March. However, the gains for the rest of the year far outweighed the losses.

2. The heat gains were 70% from the sun, 22% from the lights, and 8% from the children.

3. The lowest observed monthly-average classroom temperature when the room was occupied was about 63° F in February; the highest was about 73° F in June.

4. The mean daily fluctuation in outdoor temperature was 13° F; in indoor temperature, 7° F, and in the temperature of the inner surface of the storage mass, 2° F. On one day, a swing of 16° F was noted in the room air temperature.

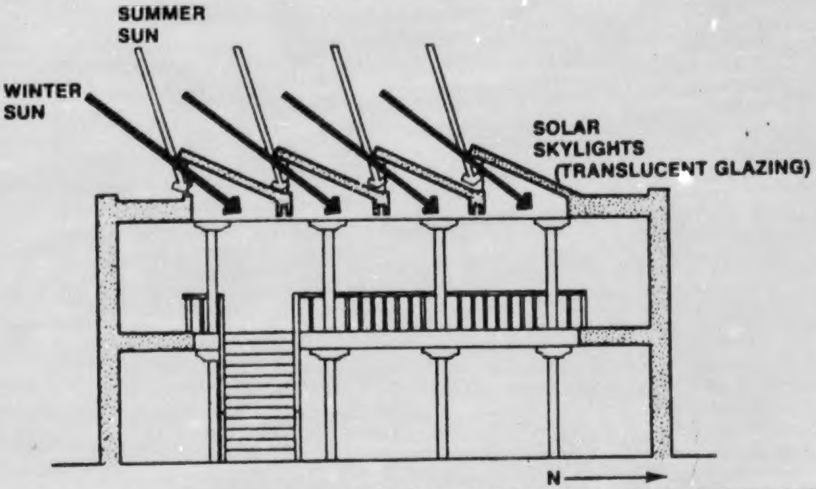
5. The minimum indoor temperature occurred at 6 a.m. when the lights were turned on; the maximum indoor temperature often occurred at about 3 p.m.

This clearly illustrates the effect masonry has in keeping indoor temperatures relatively stable.

Roof Solar Windows

Another, very different application of a direct gain concept is Maxamillian's restaurant, located in Albuquerque, New Mexico. The restaurant employs a direct gain system to supply a major portion of its winter heating needs and a natural cooling system to meet its summer cooling loads.

Its heating and cooling system consists of four south-facing sawtooth clerestories and a masonry interior (see Figure 7-17). The restaurant, originally

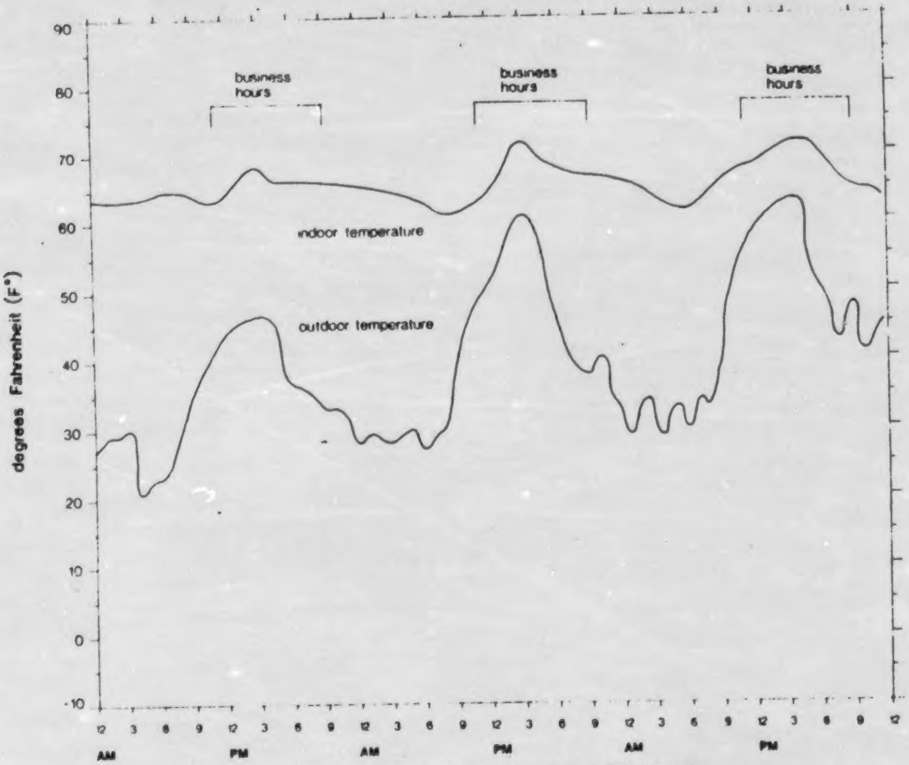


SECTION SHOWING SUMMER AND WINTER OPERATION

Figure 7-17.

an existing two-story, adobe and brick exterior courtyard of approximately 1600 square feet, was enclosed with four translucent glazed clerestories. In winter, direct sunlight entering the space is diffused and distributed over the masonry interior. This enables the masonry to absorb and store the incident energy evenly and effectively. The masonry then acts as a heat sink, storing energy during the daytime and releasing it to the space at night.

In winter, the clerestories are designed to admit enough sunlight to maintain space temperatures within the comfort range, without any auxiliary heating system. The restaurant is designed to operate between 65° and 75° F during business hours, then allowed to drop into the low 60's late at night when the space is not in use. To illustrate this, Figure 7-18 graphs restaurant temperatures for a typical three-day period in winter. It can be seen that the space maintains temperatures between 61° and 71° F; however, during business



INDOOR AND OUTDOOR TEMPERATURES—
NOVEMBER 25, 26, 27, 1977

Figure 7-18: Maxamillian's Restaurant

hours the temperature in the restaurant only fluctuated between 65° and 71° F. This means that the restaurant is slightly cool (65° F) until about 11:00 a.m. when people arrive for lunch and help boost the temperature well into the comfort range. Remember that 65° F air temperature in a radiant heated space is "felt" as being warmer than a conventionally heated space at that same temperature. To avoid the possibility of overheating in winter, the clerestories were slightly undersized to allow for the heat gains from lights, people and appliances.

In summer, cooling is accomplished by keeping the sun out and by ventilating the space at night. Most often, nighttime temperatures in Albuquerque drop into the low 60's. By opening both windows on the main level and the vents positioned high in the clerestories, a convection current is induced; cool air is drawn in through the low openings and warmed air rises out through the high vents. The masonry in the space, cooled throughout the evening by this natural flow of air, absorbs heat and provides cool interior surfaces throughout the day. Also, when outdoor temperatures and sunlight are most intense, shading devices permit only indirect light to filter into the restaurant.

During the winter of 1976-77 the restaurant operated comfortably with the sun (and people) as its only heating source.

INDIRECT GAIN APPROACHES

Passive solar buildings, which are designated as indirect gain approaches, continue use of the house to collect and store solar energy, but the sun's rays do not travel through the living space to reach the storage mass. This eliminates the direct gain temperature limitation whereby solar collection temperatures are limited by occupant comfort needs. Thus, in the indirect gain concept, a storage mass collects and stores heat directly from the sun, and then transfers heat to the living space.

There are basically two types of indirect gain systems: thermal storage walls and thermal storage roofs. The difference between the two systems is the location of the mass; one is contained in a wall and the other on the roof of the space being heated.

Thermal Storage Walls

The second generic approach is the thermal storage wall in which heat energy is stored in a wall which blocks the sun after it passes through the glazing. The wall in this case is usually painted black or a dark color to be a good absorber. It can be water held in containers, or masonry. Figure 7-19 illustrates the thermal storage wall. The state of the art is perhaps most advanced for thermal storage walls. This is because they are well known and relatively easy to handle. They are quite well characterized, and one is able to predict their performance for different climates, wall material properties, glazing treatments, wall thicknesses, and degree of thermocirculation.

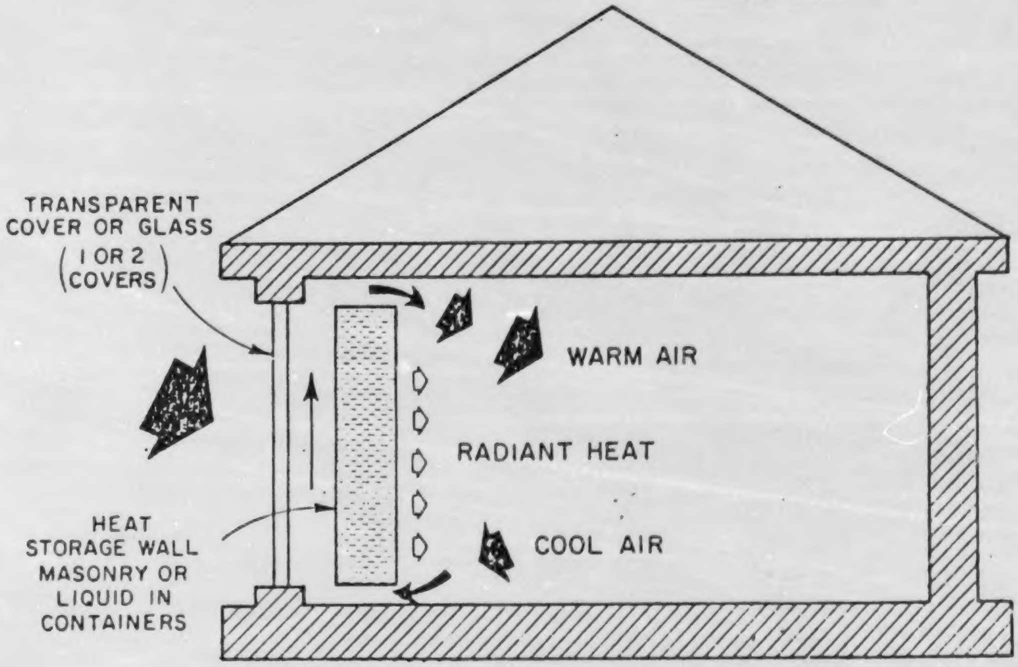

TRANSPARENT COVER OR GLASS
(1 OR 2 COVERS)
WARM AIR
RADIANT HEAT
COOL AIR
HEAT STORAGE WALL MASONRY OR LIQUID IN CONTAINERS

Figure 7-19: Trombe-Wall Design

Masonry Thermal Storage Walls: The concept of using a masonry wall immediately adjacent to the glass wall was developed by Felix Trombe and his associates in the south of France in the late 1960's, and a masonry wall is frequently referred to as a "Trombe" wall. The principle of the Trombe wall for heating room air is illustrated in Figure 7-19. As the air between the glass and masonry wall is heated, it rises and enters the room through a vent at the top of the wall. The number and size of vents can be varied. Room air enters the lower vent and is heated as it rises between the window and the masonry wall. Not all of the solar heat is transferred to the air; some is stored in the wall.

As heat is conducted through the masonry wall and the room-side wall temperature becomes greater than the room air temperature, air in the room is heated, as shown in Figure 7-20. Heat is also radiated into the room from the wall, transferring heat to interior walls, furniture, and occupants. If the room becomes too warm during the day, the lower vents can be closed to stop the circulation of air between the window and the wall. If the inside wall surface becomes too warm, the window can be shaded, or an insulating curtain can be drawn across the inside wall to stop radiant heating of interior walls.

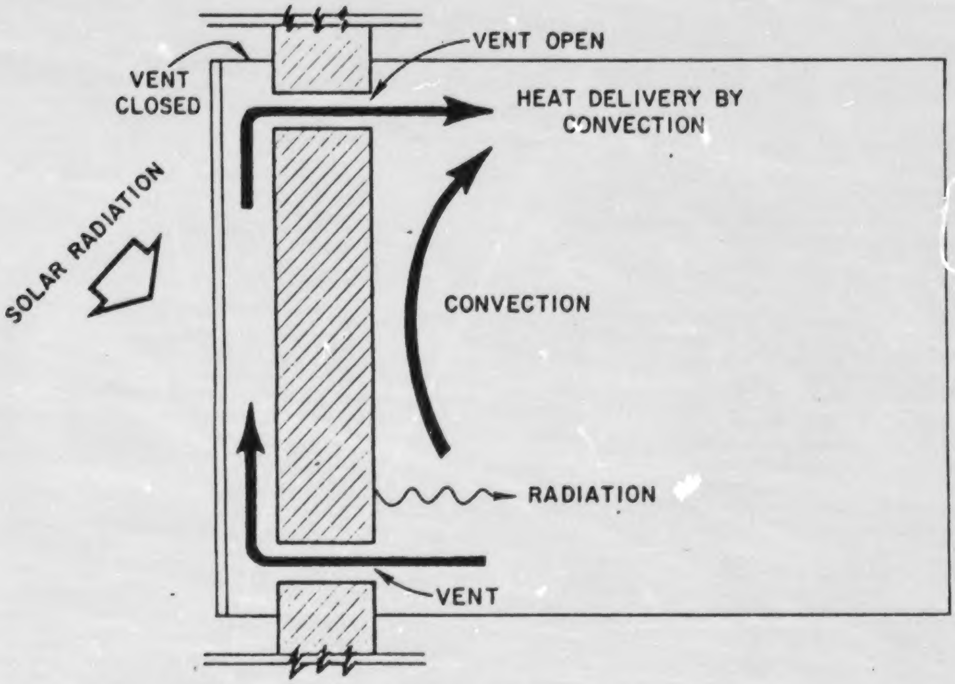


Figure 7-20: The Trombe Wall in the Heating Mode

Venting to the outside is also possible, as shown in Figure 7-20B. At night, as the air in the space between wall and glass cools, the direction of circulation reverses and if the upper vent is not closed, heat would be lost from continued circulation of the room air. During the summer, the outside vents are opened to allow the heated air to exhaust outdoors, as shown in Figure 7-21. and some cooling by ventilation can be achieved by drawing cool air from the north side of the building through the rooms.

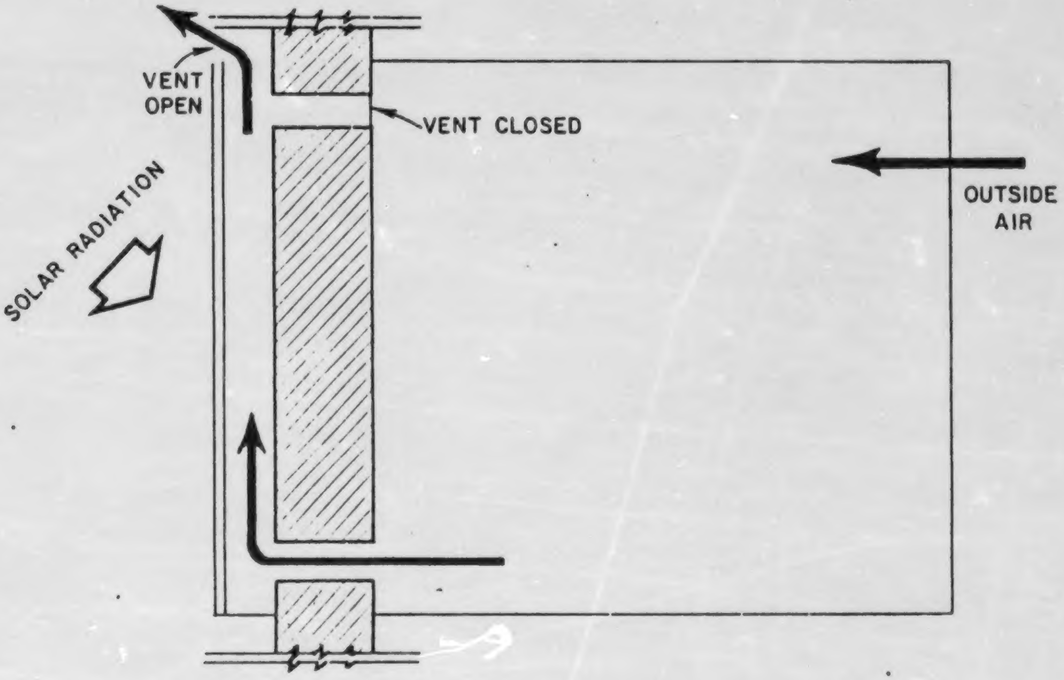


Figure 7-21: The Trombe Wall in the Ventilating Mode

A properly designed Trombe wall will have vents provided to cool the south face of the wall and to provide circulation of heat to the rooms during the day. The wall thickness need not be greater than one foot for any location. If vents through the wall to the living space are used, then dampers over the upper vents may be advisable to prevent circulation through the vents at night, which will cool the room air.

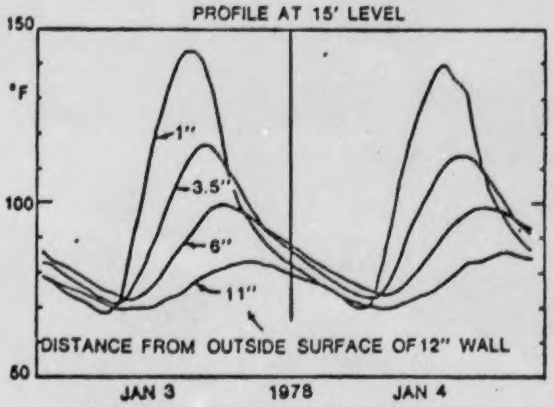
Like all indirect and/or isolated gain design approaches, the thermal storage wall circumvents two of the major difficulties with the direct gain approach, both associated with admitting sun into the living space: the high lighting levels (glare) and damage to materials in the building by the ultraviolet. Placing windows in the thermal storage wall, as was first done by Doug Kelbaugh and later by others, is one effective means of mixing design approaches.

Another major advantage of the thermal storage wall is the reduction of temperature swings, by interposing a capacity effect between the solar gain and the living zone. This is especially true if the thermal storage wall is a solid material, such as concrete, which provides a smoothing of the temperature wave as it diffuses through the wall. Data taken from LASL test rooms operated without auxiliary heat indicated the following temperature swings on a series of sunny February days.

TABLE 7-5: TEMPERATURE SWINGS

	Thermal Storage Mass, Btu/°F	Thermal Storage Surface Area/ Glazing Area	Inside Daily Temperature Swing, °F	Time of Inside Temperature Peak, pm
Direct gain room	37	2.80	38	3:00
16" Trombe wall (with vents)	32	0.84	26	4:00
16" Solid wall (no vents)	32	0.84	9	10.00
Water wall	35	1.01	25	4:00

These results are more extreme than would be observed in a passive building, since the test rooms have a large ratio of collector area to load [$\sim 4.3\ \mathrm{ft}^2_c/(\mathrm{Btu/hr}\text{-}^\circ\mathrm{F})$], and consequently, the inside temperatures average about 50° F above the outside temperature on sunny mid-winter days. Another advantage of a solid thermal storage wall is in providing a time delay between the absorption of solar energy on the outside of the wall and the delivery of that energy to the interior of the building. Characteristically, this time delay is in the order of 6 to 12 hours so that the maximum heating generally occurs in the evening, at a time when it is most needed in a residential application. This time delay effect is quite evident in every thermal storage wall which LASL has monitored. Temperatures measured at different points within the wall are shown in Figure 7-22, which appears on the following page, in data taken in Bruce Hunn's thermal storage wall. Two things should be noted on this plot: the increase in delay time of peak temperature, and the decrease in the peak temperature, as the wave progresses through the wall.



Temperatures measured in a two story thermal storage wall. The wall is made of 12" hollow concrete block with holes filled with mortar. The wall is double glazed and has no vents.

Figure 7-22: Bruce Hunn Trombe Wall

The time delay effect allows for flexibility in thermal design. The building can be heated by direct gain or thermocirculation during the day and by the wall at night. The following table lists the characteristics of a solid concrete wall during sunny days with double glazing on the outside.

Thickness, inches	Inside Surface Temperature Swing, °F	Time Delay of Peak on the Inside, hours
8	40	6.8
12	20	9.3
16	10	11.9
20	5	14.5
24	2	17.1

The thickness of solid wall, which gives the maximum annual energy yield to the building, is about 12", independent of climate. However, such a wall has to be cold and uncomfortable during long cloudy periods. Thus, the designer is led to consider thicker walls, which provide more storage and a more stable inside surface temperature. However, the major problem with Trombe walls is high cost of construction plus the related fact that they use up valuable space within the building.

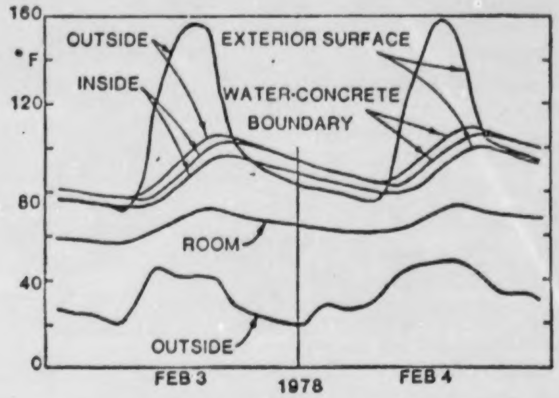
Water Thermal Storage Walls: A second indirect gain passive solar building type is identified as the water thermal storage wall, in which the sun's rays are intercepted beyond the collector glazing by a water storage mass, then converted into heat and dirtributed by convection and radiation to the living space. The water thermal storage wall involves the same principles as the mass Trombe wall, but employs a different storage material and different methods of containing that material. These variations offer a variety of methods for the integration of the Trombe passive solar concepts into the building vocabulary.

The requirements for the water thermal storage wall are again a large glazed area and an adjacent massive heat storage. However, the storage is now water, or another liquid, contained in a variety of containers, each representing different heat exchange surfaces to storage mass ratios. Larger storage volumes provide greater and longer term heat storage capacity, while smaller contained volumes provide greater heat exchange surfaces, and thus faster distribution. This tradeoff between heat exchange surface versus storage mass has not as yet been explored in depth; however, many container variations have been built, including components such as tin cans, bottles, tubes, bins, barrels, drums, bags, and complete water walls. The selection and interrelationship of storage materials, then, is necessary to the effective operation of the water thermal storage wall.

In considering the control of heat distribution in a water thermal storage wall, one must be aware that thermal transfer is rapid within a convective body of water, and radiant distribution from a solar heated water storage wall to a living space is almost immediate. This is in contrast to the longer time-lag property of the mass Trombe wall. Therefore, if heat is undesirable until the cooler evening hours, the water thermal storage wall system requires some storage-distribution control. The addition of insulation between storage and the living space, combined with high and low vents for air circulation, provides one control solution, by allowing the system to rely solely on convective distribution.

Aside from this distribution consideration, the controls for the water thermal storage wall are similar to those of the mass Trombe wall. Overheating of the storage mass should be prevented by shading, and unnecessary heat loss from the storage mass should be prevented by exterior insulation. In addition, the use of operable vents which open to the outside, will induce summer ventilation as described for the mass Trombe passive solar building.

As with the mass Trombe wall, the water thermal storage wall has a major problem in high cost of construction, plus the related fact that they use up valuable space within the building. Various types of approaches to water thermal storage walls have been implemented in an attempt to overcome these difficulties. Water in containers of various shapes and sizes has been used effectively. One interesting design is a water-loaded wall consisting of cast concrete tanks of 4' x 8' x 10" outside dimensions. The tank wall is 2" thick leaving a 6" cavity. After installation, a plastic bag is put in the cavity, filled with water and sealed. Data taken by LASL on this wall are shown in Figure 7-23.



Reflector-augmented water-loaded wall; temperatures are measured at the outside surface, at the boundaries between the water bags and the 2" concrete walls, and at the inside surface. The wall is double **glazed and** has no thermocirculation vents.

Figure 7-23: First Village, Unit 4.

The wall is covered outside at night by a hinged insulating-reflecting door. It was concluded that future walls of this type should be made much thicker to provide longer heat storage and maintain the wall warmer and thus more comfortable during long cloudy periods.

Thermal Storage Roofs

A third indirect gain building type (sun to storage mass to living space) for which examples have been built is the thermal storage roof, or the "Roof Pond". In the Roof Pond building type, the passive collector-storage mass has been relocated from the floor and wall of the building into the roof for radiant heat distribution to the living space (see Figure 7-24). This move involves several new principles of physics, and thus different design considerations.

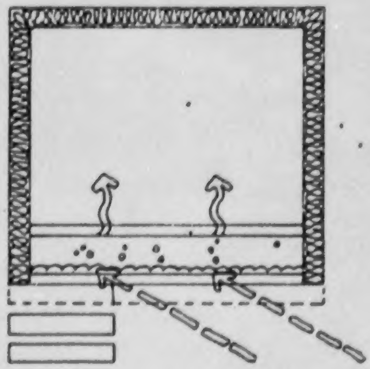


Fig. 7-24: Roof Pond

Requirements: The Roof Pond system requires a body of water to be located in the roof, protected and controlled by exterior movable insulation. This body of water is exposed to direct solar gain, which it absorbs and stores. Since thermal storage is the ceiling of the house, it will radiate uniform low temperature heat to the entire house in both sunny and cloudy conditions. Distribution of solar heat from the Roof Pond is by radiation only, so proximity of the ceiling to the individual being warmed is important, since radiation density drops off with distance. This suggests that the storage mass be uniformly spread over all living spaces and that ceiling heights not be raised from the normal.

Secondly, movable insulation is generally required to reduce unwanted heat losses to the environment on sunless winter days and nights and unwanted heat gain in summer. The Roof Pond is also well suited for natural summer cooling in regions where day-night temperature swings exist. Cooled down on summer evenings by exposure to the night air, the "ceiling" water mass can then draw unwanted heat from the living and working spaces during the day, taking advantage of the temperature stratification to provide passive cooling.

Variations: In listing the elements immediately necessary for the Roof Pond, collector glazing was not a requirement. However, considerable loss of water can occur due to daytime evaporation, unless some sort of cover is provided for the water mass. The use of transparent covers and glazing panels, or water bags over plastic liners, are existing solutions to both evaporation and leakage. These examples also suggest that several forms of water storage will be evident in the Roof Pond building type.

Similar to a Water Thermal Storage Wall, the tradeoffs in storage design are between the heat exchange surface and the storage mass capacity. Another significant variation seen in this building type was developed because the horizontal location of the Roof Pond seemed to be better suited to lower latitudes, with high winter suns and no snow buildup. A glazed attic enclosure, employing reflectors to maximize the lower sun angles, alleviated the snow loading and freezing problems to adapt the Roof Pond passive solar building type to many more regions.

INDIRECT GAIN APPLICATIONS

Thermal Storage Walls

A passive approach to solar heating using the Trombe (thermal storage) wall technique is utilized in a house in Princeton, NJ, designed, built and occupied by Doug Kelbaugh and his family. Princeton (located slightly north of 40° N latitude) normally experiences 5,100 heating °F-days and receives about 55% of the possible sunshine during the winter.

Among the advantages which the owner feels a Trombe wall affords are long life, low operating temperatures, substantial summer cooling, no fans, pumps, and few moving parts. In addition, the vertical collector is self-cleaning and provides a nearly optimal collection angle when there is snow on the ground. Furthermore, the wall may be architecturally integrated with the remainder of the building and permits the use of a variety of backup systems. Finally, perhaps the greatest asset of such a system is the simplicity of its design, maintenance, operation, and understandability.

Design of House: The design of the house was undertaken by the owner, Doug Kelbaugh, an architect and solar consultant. The task he set for himself was to design a house with $45,000 maximum construction cost, a Trombe wall, a large interior space, three bedrooms, a fireplace, a greenhouse, and a usable yard on a small lot. The owners found one of the few remaining building lots in town and filed for a zoning variance, which was granted without opposition.

This variance permitted the house to be situated on the northern boundary of the 60' x 100' lot, thereby providing unshaded access to maximum available sunlight and also allowing the large tree in the center of the lot to be saved. At the same time, this arrangement provided the desired large exterior yard.

Figure 7-25 illustrates the floor plans for the first and second floors of the house. The ground floor has been kept simple (one large, continuous space) with the kitchen partially separated from the living and dining area by the stain. On the second floor, the three bedrooms are strung along the concrete wall with separate rooms for toilet, bath/shower, and utility along the east wall, which has the only plumbing in the house.

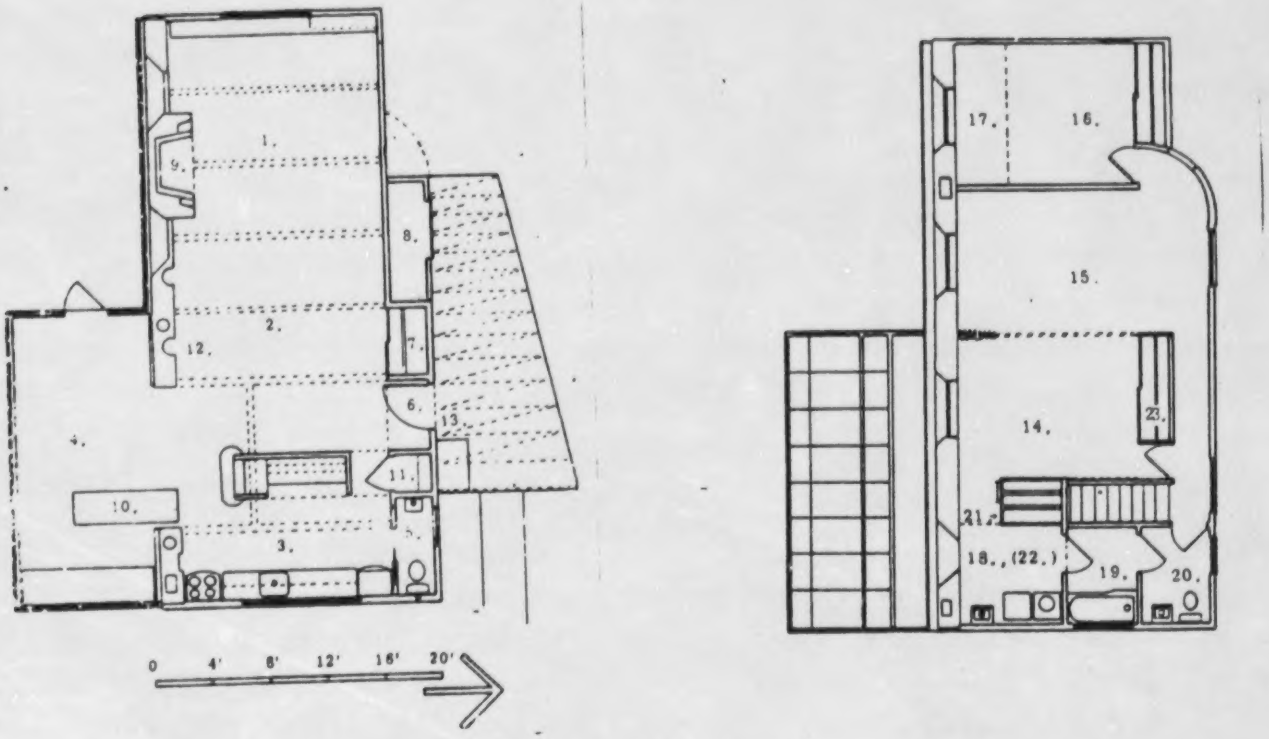


Figure 7-25: Floor Plans

(a) Ground floor plan
(b) Second floor plan

(1) Living
(2) Dining
(3) Kitchen
(4) Greenhouse
(5) W.C.
(6) Entrance
(7) Coat closet
(8) Garden storage
(9) Circulating fireplace
(10) Trap door to cellar
(11) Utility closet
(12) Candle niche
(13) Arbor
(14) Master bedroom
(15) Study
(16) Child's bedroom
(17) Sleeping loft
(18) Sink, bidet, laundry
(19) Bath
(20) W.C.
(21) Linen closet
(22) Storage loft
(23) Movable closet

A greenhouse leans against and works sympathetically with the Trombe wall. The interior of the house conveniently adjoins the greenhouse through a wide arch. There are intentionally no double-height rooms or any other spatial tours de force in order to keep costs down as well as to make air circulation easier to predict and control. A minimum amount of window area is included, particularly on the north wall, where windows lose more heat than they collect.

The north, east, and west walls are standard wood frame with rough sawn cedar plywood on the exterior and sheetrock on the interior. The cavities (4.5" on the first floor, 3.5" on the second floor, and 9.5" above the ceiling) have been blown full of cellulosic fiber (recycled newspaper) to achieve an R factor of 18 in the walls and 40 in the roof. Styrofoam 1" thick has been placed on the outside of the foundation wall around the perimeter to a depth of 2'.

Solar Heating System: Figure 7-26 illustrates a simplified diagram of the solar heating system of the house. The basis for this system is a Trombe wall constructed of 15" of concrete which has been painted with a special black coating (3M Nexel over masonry conditioner). In front of the wall are two sheets of

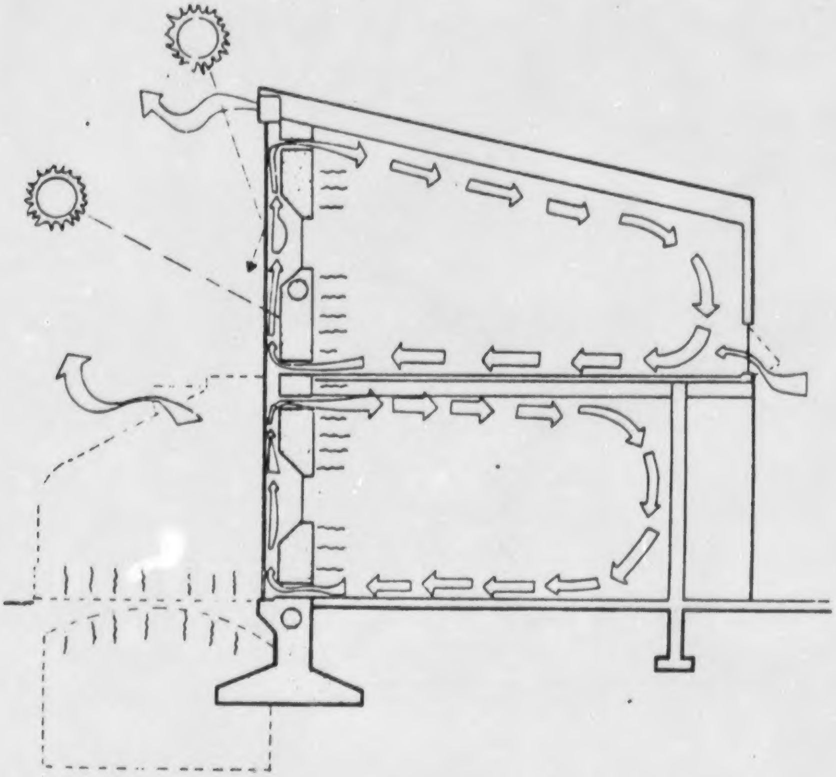


Figure 7-26: Solar Heating System

of double-strength window glass. The total collection area is roughly 600 ft^2 (plus the greenhouse). Vents in the wall at the top and bottom of each floor level are part of a natural convection loop which permits circulation of the air.

The heat loss for the building is calculated by conventional analysis to be about 65,000 Btu/hr at 0° F outside temperature. The backup heating system consists of a conventional, gas-fired, hot-air furnace with a net delivery of 58,000 Btu/hr. The backup system is separate and distinct from the solar system, although its ducts are cast in the concrete wall. One branch leaves the wall to supply heat to the bathrooms (which are isolated from the concrete wall). Three 250 watt heaters were also installed in the bathrooms to provide instantaneous supplementary heat.

A lean-to greenhouse, which acts sympathetically with the solar wall, was added to grow ornamental and edible plants. Its thick, concrete floor is painted black to collect and store heat to heat the cellar as well as the greenhouse. The design also provides substantial summer cooling. Four fans at the eave exhaust heat buildup at the southern wall and ventilate the entire house by pulling air across the rooms from windows on the north wall. By ventilating the concrete wall at night, the wall is cooled to absorb heat from the rooms on the following day. The greenhouse is shaded in the summer by slat blinds drawn over the glass and also by two large deciduous trees.

The total system provides heat to an area of 2,100 ft^2 and a volume of 19,000 ft^3.

Modifications to the Solar Design: In response to a number of problems that were discovered during the first winter of occupancy, several modifications have been made to the solar design in order to improve the effectiveness of the solar heating system. One problem encountered was that of reverse thermosiphoning, whereby warm air at the ceiling height would leave the room at night through the upper vents in the concrete wall, wash down the exterior glass wall, and reenter the room through the lower vents at a lower temperature than it left the room. This problem was solved simply and effectively by installing a passive damper consisting of a screen (on the inside of the concrete wall) covered by a light cloth, which permits air circulation in one direction (inward) only. Another problem encountered was that of heat migration to the second floor. Because there is an open stairwell, and the backup system seldom cycles air, the warmer air has a longer time to rise and collect upstairs. The average winter room temperature upstairs was about 5° F higher than downstairs. This problem has been addressed by putting a door at the top of the open stairwell.

Problems were also encountered in the greenhouse. During the first winter, excessive heat losses were experienced in the greenhouse. In fact, hourly heat loss in the single-glazed, 200 ft^2 greenhouse was about 32,000 Btu, which represents a sizable proportion of the 75,000 Btu/hr total for the entire house. Subsequently, a second layer of glass has been added, which is estimated to cut heat loss by about 15,000 Btu/hr.

Another problem encountered in the greenhouse was that of excessive temperature fluctuation. The greenhouse temperature often swung from 75° F on a sunny winter afternoon to 50° F that night. Eight 5-gallon water drums painted black have subsequently been added in order to flatten the diurnal temperature curve and to double as plant benches.

Curtains and shutters have also been added over several windows.

Construction and Cost: Design of the house took about one year from conception to groundbreaking, although the actual design stage was much shorter since considerable preliminary effort was expended in researching the Trombe wall and getting municipal approvals. The basic construction required about one year to complete, but the owners moved in during July 1975, approximately nine months after construction had commenced.

The entire cost of the house was estimated to be $55,000 plus the owner's labor. The additional initial cost of the house directly attributable to the solar heating and cooling system is approximately $8,000 to $10,000. This figure includes a modest allowance for the cost of the wall which the Trombe wall replaces. In addition, several thousand dollars could be saved if solid concrete block was used instead of poured-in-place concrete. It is difficult to estimate this cost, since the system is so closely integrated into the design of the house.

Performance: Two winters of operating experience have been obtained since the completion of the house. The first winter (1975 to 1976) was quite mild, about 4,500° F-days; the second winter (1976-1977) was more severe, about 5,400° F-days. However, the modifications made to the house between the first and second winters resulted in similar space-heating requirements for the two winters by significantly reducing heat loss from the house.

Temperature Performance: Instrumentation provided by Los Alamos Scientific Laboratory has been installed to monitor the temperature performance of the Trombe wall. Figure 7-27 depicts some illustrative data taken during the period from March 6 to March 8, 1977.

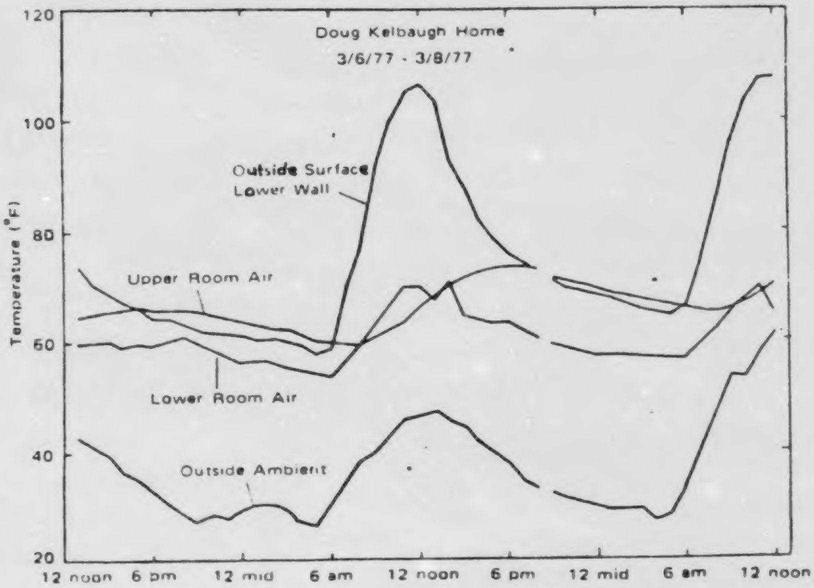


Figure 7-27: Trombe Wall Temperatures.

Temperature fluctuation was tolerably light, although vertical stratification is sometimes pronounced. A 5° to 10° F swing in the indoor temperature during the 24-hour cycle allows the concrete wall to collect and discharge its heat. Daytime settings were between 60° and 64° F and the nighttime setting was 58°F. The seasonal low indoor temperatures were 58° F downstairs and 62° F upstairs, and the corresponding highs were 70° downstairs and 75° upstairs. The estimated downstairs average was about 63° F while that for upstairs was 67° F. A heatilator wood fireplace provided additional heat two or three times a week, but was not considered in the calculations because it combusts warm room air and pulls in cold outside air, which offsets most of its heat contribution during mild months and all during cold months.

Operational Cost: The table below illustrates the relative contributions of the various heating sources and assesses the savings attributable to the solar heating system. Quantities in the table are based on an average room temperature of 65° F in the living area and 58° F in the greenhouse. For the first winter, the heat loss for the design was calculated to be 27,500 Btu/degree-day. As indicated in Table 7-6, the solar heating system reduced the space heating cost 76%, resulting in a $330 savings over the cost of heating by fossil fuels alone.

TABLE 7-6: PERFORMANCE SUMMARIES FOR FIRST TWO WINTERS

	1975-76 (4,500° F-days)	1976-77 (5,400° F-days)
Heat loss, Btu	124,000,000	129,600,000
Miscellaneous heat gain, Btu*	17,000,000	17,000,000
Space heating requirements, Btu	107,000,000	112,600,000
Gas furnace contribution, Btu	26,000,000	18,000,000
Solar contribution, Btu	81,000,000	94,600,000
Savings, $**	330	379
Fuel bill (space heating), $	108	72

*From stove, clothes dryer, lights, hot water, and occupants.

**Based on 31¢ per ccf of natural gas or 40¢ per gallon of oil for 1975-76 and based on 32¢ per ccf of natural gas for 1976-77.

Modifications made to the system between the first and second winters improved the system so that the calculated heat loss for the design was reduced to 24,000 Btu/degree-day. Consequently, the space heating requirements were approximately the same for the second winter as for the first, despite the fact that the second winter was more severe. The solar contribution for the second winter was greater, reducing by 84% the space heating bill for a net savings of $379.

Thermal Storage Roofs

A three-bedroom house located in Atascadero, CA has been designed and built by Harold R. Hay, utilizing a system which he invented and patented, that makes use of roof ponds and movable insulation for solar heating and cooling. The system (known as Skytherm) provides 100% heating and cooling in an area where temperature extremes have varied from 10°F in winter to 110°F in the summer.

Fundamentally, the Skytherm system uses a metal roof which also serves as the ceiling of the room below. The thermal resistance of the roof deck is negligible (since it is made of relatively light gauge steel), and the water ponds supported by the deck are encased in thin plastic bags which also have no measurable thermal resistance. During the winter, sliding insulating panels expose the bags to sunlight during the day and cover them at night, controlling heat loss. The bags in turn radiate their heat directly to the space below through the metal roof.

During the summer, the panels protect the roof ponds from the sun during the day, but expose them to the sky at night, when the ponds radiate their heat outward and thereby cool the house below. The Atascadero house is the third prototype of a natural air-conditioning system and has been extensively evaluated by a team from California Polytechnic State University, San Luis Obispo, under a grant from the U. S. Department of Housing and Urban Development (HUD). The house has demonstrated its ability to stay warm in winter and cool in summer without the use of any electricity other than that used in food preparation, hot-water heating, lighting, and the daily movement of the insulating panels.

Design of House and Solar Heating System: The initial full scale test of the Skytherm system was conducted in Phoenix, AZ, in 1967-68. The Phoenix test confirmed the capability of the design to maintain inside temperatures between 68° to 82° F with no supplementary heating or cooling in a climate with outdoor temperatures ranging from freezing to 115° F. The Atascadero project was conceived to confirm the Phoenix test results in a regular dwelling occupied by an average family, and to evaluate design improvements and automation.

Figure 7-28, shown on the following page, illustrates the floor plan for this 1200 ft^2 house. Below the roof line, it is very similar to a typical American custom designed house in both plan and construction techniques. The foundation is reinforced concrete with a slight increase in the size of footings over conventional designs to accommodate the loads transmitted from the roof pond. The floor is a reinforced concrete slab, and polystyrene insulation has been applied around the exterior perimeter of the footing walls and the slab edges. The interior walls running east and west through the house are concrete block filled with sand and grouted where required by code in this zone 3 earthquake area. The exterior walls consist of standard wood frame with R-11 insulation.

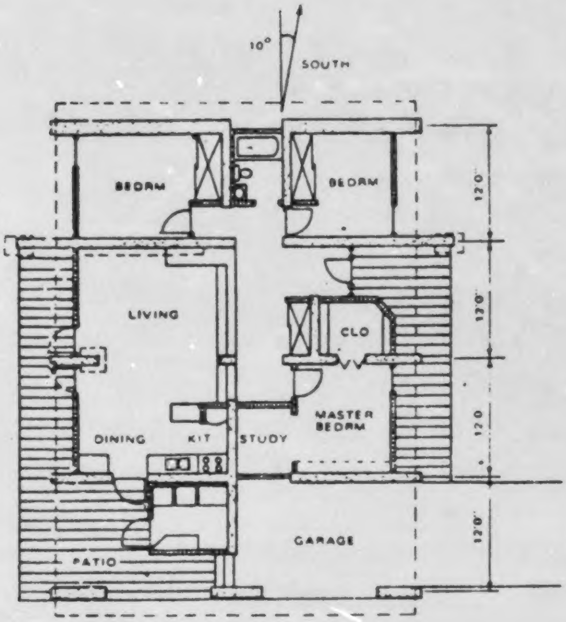


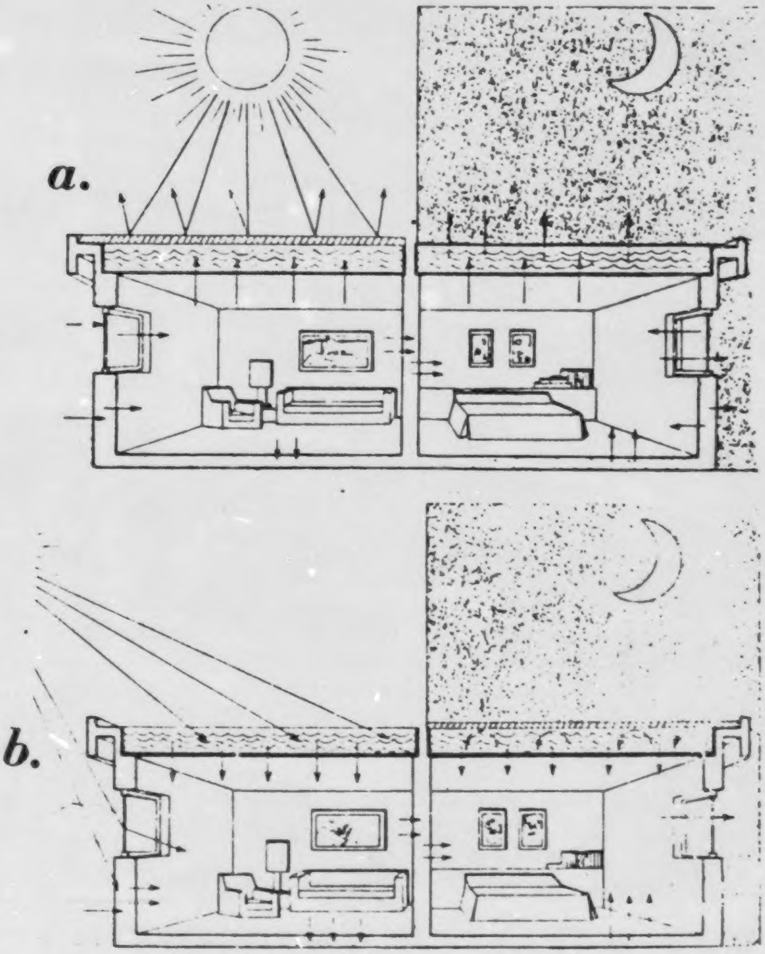
Figure 7-28: Floor Plan

The roof is a premanufactured, ribbed, sheet steel deck spanning the concrete block walls and lintels at 12' intervals. The deck (which is waterproofed with asphalt emulsion coating and a fiberglass mat) acts a structure, heat exchanger, and finished ceiling. PVC bags 20 mils thick are placed directly on the deck and filled with water to serve as collector, storage, and heat dissipator. An additional top layer of transparent PVC was added and the space between this layer and the PVC bags is inflated to provide a greenhouse effect cover. Movable insulation panels (custom made by the local plumbing company) are fixed to metal beams and serve as the thermal valve for the system. The panels, in 8' by 12' modules, stack over the garage/utility room/lakeview terrace area when not covering the roof pond. Operation of the panels has been automated by a differential thermostat-thermal model control system. The total collector area is 1,100 ft^2 and the roof pond has an average depth of 8.5" (for a total capacity of approximately 6,000 gallons).

The south wall contains no windows (except in the bathroom), and all windows in the house (comprising 21% of the total wall area) along with the exterior glass doors are double pane. Thermal losses through the deck, the ceiling, and the exposed roof of the carport were reduced by insulating the underside of the deck in the garage and carport with 1" thick polyurethane metal building insulation. The top of the deck was also insulated with 2" thick polyurethane metal building insulation for a distance of 4' out from the roof pond. In addition, the ceiling of the full bath was insulated to prevent condensation during summer months.

Solar Heating System Operation: Figure illustrates the basic concept by which the Skytherm system provides summer cooling and winter heating. In winter,

Figure 7-29: Solar Operation



(a) Summer
(b) Winter

the insulating panels are open by day and closed by night in order to collect and retain the maximum solar energy. The collected heat is radiated uniformly downward from the ceiling to heat the spaces below. Heat from the ceiling is transferred to the rooms primarily by radiation to the floor and walls; convection from the ceiling to the room air plays a relatively small role in the heat transfer process.

In summer, panel positions are reversed in order to reject solar heat, while the water bags absorb heat (through the ceiling), which infiltrates or is generated in the living area. The stacked panels expose the water bags at night and allow the water to be cooled by convection and radiation to the cool night sky. When necessary, the water bags may also be flooded with more water to add the cooling effect of evaporation.

Construction and Cost: The total building costs of the house (excluding land, landscaping, and money costs) are $39,500. The house contains 1,192 ft^2 of interior space and 384 ft^2 of covered exterior space (carport and lakeside patio). Counting covered exterior square footage at one-half the cost for this prototype, the house cost is $27.80 per square foot. Custom house construction with unique characteristics generally runs about $22.50 (1973 prices) in this area.

Performance: From May 1, 1974 through September 23, 1974, the Skytherm nocturnal system maintained a medium indoor temperature of approximately 72° F, while the outdoor daytime daily maximum average temperature approached 88° F (Figures 7-30, 7-31, and 7-32). No electricity was used for any type of supplemental cooling. Thus, over the winter and summer test period, Skytherm has operated without the use of any energy for supplemental heating or cooling.

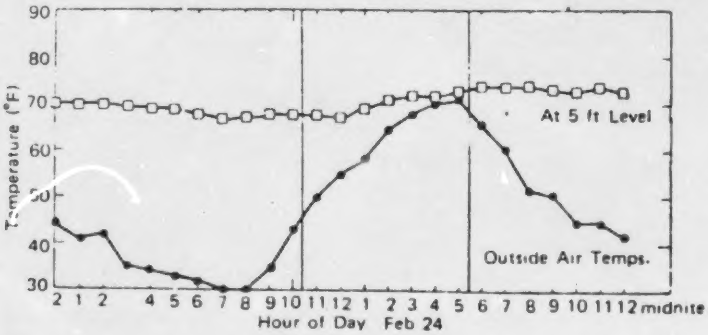


Figure 7-30: Typical Heating Day.

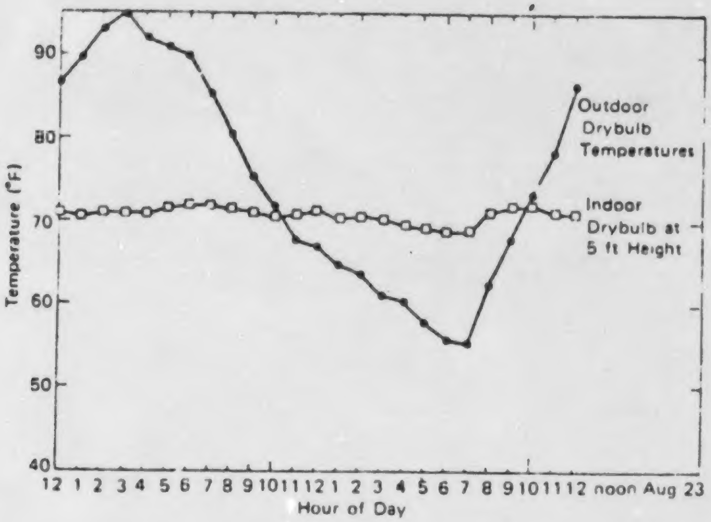


Figure 7-31: Typical Cooling Day

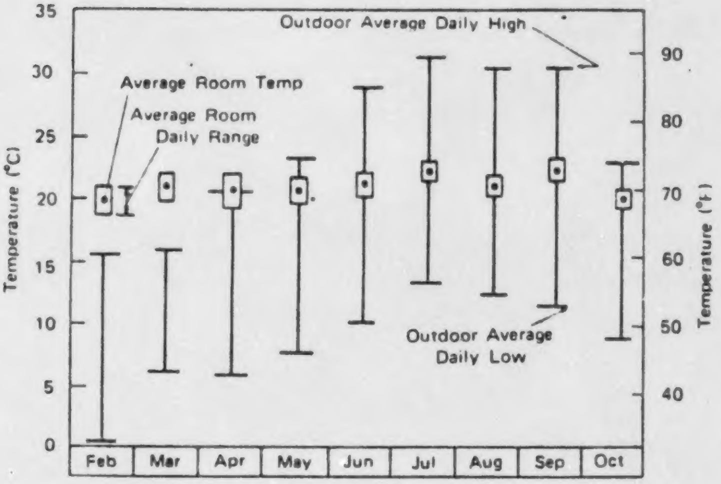


Figure 7-32: Average 9-Month Performance.

The thermal performance of the house was very positive. The movable insulation system supplied 100% of the heating and cooling requirements of the building during the test months. During this time, the system was able to keep the indoor temperature between the extremes of 66° and 74° F except during special test periods or times of prototype breakdown. Even during these exceptional periods the temperature never got higher than 79° F or lower than 62° F. The indoor temperature at the 5' level cycled less than 4° F daily. The vertical temperature stratification in the living space was usually less than 5° F in the winter, and less than 1° F in the summer.

The highest ambient temperature experienced during the test period was 100° F in July. The 24-hour average daily temperature during this month was 73° F, with a daily range between maximum and minimum of about 32° F. The lowest temperature recorded was 26° in February, 1974. For this month, the average daily ambient temperature was 47° F.

Although the months of November, December and January, 1973-1974 are not covered in the test data reported herein, computer model analysis showed that the system would probably have been able to keep the indoor temperature above the 66° F minimum reported above. The system was operated with both an unglazed and single glazed configuration by means of an inflatable plastic cover. Inflation was necessary in the winter months in order to keep the indoor temperature up to the reported levels.

Without inflation it was estimated that the indoor temperature would have dropped to near 60° F in the early morning hours. In the summer, it was necessary to deflate the cover in order to keep the living space temperature from approaching 80° F and putting the confort conditions into the slightly warm region of the comfort standards. However, better ventilation and correction of panel seals would probably have allowed the system to have operated all year in the inflated configuration.

The largest monthly average heating load handled by the system was 124,000 Btu/day in February. The largest monthly average cooling load was 168,000 Btu/day during July.

The experimental house had an overall heat transfer coefficient of about 9,500 Btu/degree-day (excluding roof) and an equilibrium temperature (ambient temperature for which no heating or cooling is required) of about 62° F. The collector area was 1,110 ft^2, about the same as the floor area. The roof pond average water depth was about 8-1/2", corresponding to about 6,000 gallons of water.

Operational Cost: Studies indicate that the breakeven points lie between $1.50 and $2.50 per square foot in premium cost and between $16.50 and $23.00 in monthly utility savings. An approximate average would provide a breakeven point at $2.00 per square foot premium and $24.00 per month in heating and cooling costs saved.

This means that if Skytherm costs $2.00 per square foot more to build than a conventional house, and if conventional utilities for heating and cooling are $24.00 per month, the final investment in each house is the same. (For a complete analysis of this study, see "Research Evaluation of a System of National Air Conditioning," California Polytechnic State University, January, 1975, HUD Contract No. H2026R, P 168 to 178).

ATTACHED SUNSPACE

A mix of the direct gain and thermal storage wall concepts is the solar greenhouse. Here one builds a greenhouse onto the side of a building with some kind of thermal storage wall between the greenhouse and the house. The temperature in the greenhouse, of course, does not require very good control, just as long as the plants are not allowed to freeze. A more general description would be to call the greenhouse a "sunspace".

The attached sunspace passive building type collects solar radiation in a secondary space, which is separated from the living space, and also stores heat for later distribution. This sunspace (see Figure 7-33) offers both the potential separation of the collector-storage system from the living space, or the direct gain live-in situation which maximizes the use of low temperature solar gain. Thus, in concept, a sunspace passive solar system is midway between a direct gain system, in which the living space is the collector of heat, and a mass or water thermal storage wall, which collects heat indirectly for the living space. An atrium, a sun porch, a greenhouse and a sunroom all represent potential examples of a sunspace.

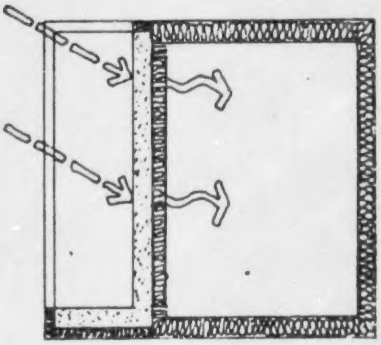


Fig. 7-33: Sunspace

Requirements and Variations

The requirements for a sunspace passive solar building type center on the glazed collector space, which must be both attached yet distinct from the living space. Provided with a strong southern exposure, the collector space must be thermally linked to a solar storage mass for heat retention and later distribution. The sunspace can be variable in its spatial and functional relationships to the primary living spaces of the building. It may vary from a minimum addition to a building with one small contact surface, to extending the entire south side of the building, to being contained within the building with an interface of several sides. The specific location of the sunspace will depend on the building design, spatial organization, and sun orientation.

A storage mass is also necessary in the sunspace type to retain heat for non-sunshine hours. Massive floors, walls, benches, rock beds, and covered pools of water can all provide effective solar heat storage, and can also be placed within reach of the winter sun for additional heat storage. If the sunspace is to serve as a greenhouse additionally for growing plants, the temperature restrictions set for the direct gain type for comfortable living conditions would be reestablished for the sunspace type. In the case of an indoor swimming pool, storage temperatures must also be limited to meet swimmer comfort. Otherwise, the unoccupied sunspace can store temperatures equal to the capacity of its storage materials, providing a controllable heat supply for the adjacent living spaces. When temperatures within the sunspace are not too hot for comfortable live-in conditions, the sunspace could then be occupied for more efficient direct gain heating.

Controls

The most mandatory control consideration of this passive solar building type is the design of the link between the sunspace and the living space. The one, two, three or four walls which interface a sunspace and living space require built-in flexibility, in order that these spaces can be thermally connected and separated as desired. The kind of distribution: radiation, convection, or conduction will be determined by these interfaces, and differentiate the Sunspace passive solar building type from the Direct Gain type. In addition, as in other passive solar building types, shading should be provided to prevent overheating of glazed spaces during the summer; and some form of movable insulation would prevent unnecessary heat losses on winter nights or cloudy days. Humidity control is also an important consideration to prevent molding within the storage mass in the plant or water occupied Sunspaces.

ATTACHED SUNSPACE APPLICATIONS

First Village is a small, planned environmental community located 6 miles south of Santa Fe, NM. All homes in the community are solar heated, and all employ water-saving technology as well. Unit 1 is a 2,300 ft^2, two-story home which employs passive gain principles along with active solar collecting and storage devices to accomplish its space-heating. All rooms face onto a large, triangular-shaped, 20' high greenhouse located on the south side of the building. The south wall of the greenhouse is constructed entirely of glass, and the other two walls are constructed of adobe, providing thermal mass for the solar storage and separating the heat collection area of the greenhouse from the living spaces behind them.

Heated air from the top of the greenhouse is circulated by fans through two rock beds situated beneath the house and then back into the greenhouse. The heat stored in the rock beds radiates through the floor, supplementing the heat from the greenhouse at night and on sunless days. Backup heating is provided by baseboard electric heaters regulated by individual thermostats in each room. In addition, a separate flat plate collector array is located near the house for domestic hot-water heating.

Design of House and Solar Heating System: The solar design, utilizing a south-facing greenhouse, mass walls, and fan powered radiant rock beds, is illustrated in Figure 7-34, which appears on the following page.

The L-shaped house features three bedrooms and two baths on the second floor, and all of the bedrooms open onto a balcony which overlooks the greenhouse. On the first floor, a breakfast nook is located at the southeast corner to catch the early morning warmth, and the living room is conveniently located at the southwest corner to accept the late afternoon sun.

The south facing is provided with approximately 400 ft^2 of thermopane mounted at a 60^o angle. The triangular-shaped floor area has a central circular staircase located in the north corner with a vent window at the top. This staircase provides access to the second floor and also acts as a chimney to

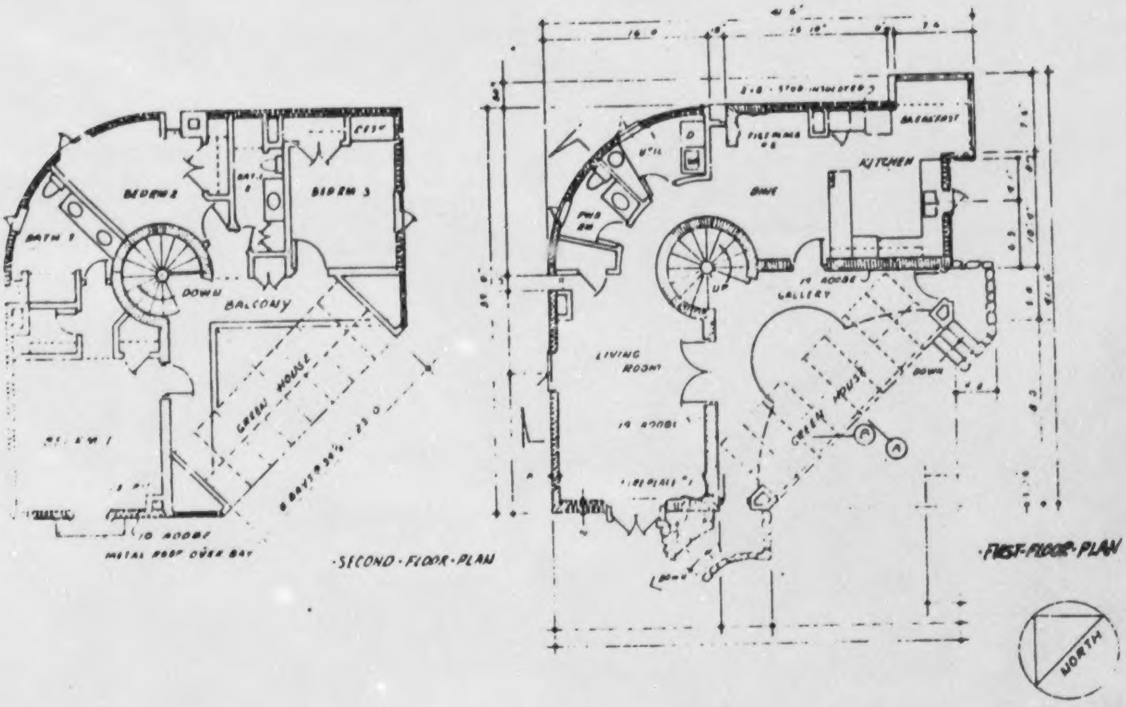

BDRM 2
BATH 1
BATH 2
BDRM 3
DOWN
BALCONY
GREEN HOUSE
10 ADOBE
METAL ROOF OVER BAY
·SECOND·FLOOR·PLAN
KITCHEN
BREAKFAST
DINE
GALLERY
UP
LIVING ROOM
14 ADOBE
FIREPLACE
GREEN HOUSE
DOWN
·FIRST·FLOOR·PLAN
NORTH

Figure 7-34: Floor Plan

cool the space in summer. The south wall of the greenhouse is entirely glass; the other two walls are adobe (mud bricks 4" thick, 10" wide, and 14" long, set with mud mortar). The wall is 14" thick at ground level and 10" at the upper level. The adobe walls provide the thermal mass for solar storage and separate the heat collection area of the greenhouse from the living spaces.

One distinguishing feature of this house is that the heat collection area is not used as a day-round living space. Although the temperature in the greenhouse may drop to 45° on a cold (5° to 15° F) winter night, experience has shown that most plants have no trouble with this environment. The north-facing side of the house is sunk 4.5' below ground level, and the below-grade walls are constructed of 8" concrete block with all of the cells grouted with cement. These walls are waterproofed with plastic roofing cement and have 2" of rigid polystyrene stuck to the tar.

The above-grade walls are constructed of 2 by 8" stud frame on 16" centers and are insulated with a layer of 1.5" fiberglass batt along with a layer of 6" fiberglass batt applied with the vapor barrier on the interior of the wall. In addition, the rear wall is rounded to provide less resistance to harsh winter winds.

Figure 7-35 illustrates a simplified heating diagram for the house. The solar heating system has two major components. The principal system uses passive gain through the south-facing glass to provide direct gain to the greenhouse space during the day and also to heat the two-story adobe mass wall that separates the greenhouse from each of the living spaces.

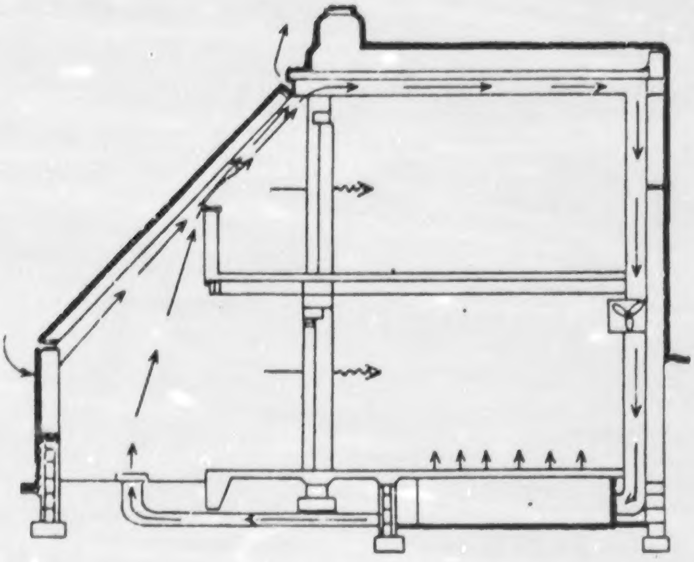


Figure 7-35: Solar Heating System

The heat absorbed into this mass wall during the day eventually works its way through the wall into the living spaces at night. One advantage of the mass wall is that it acts to average the fluctuations between the surface temperature on the darkened adobe mass wall during the day and the temperature in the unshuttered greenhouse at night. These temperatures range from a 110° F surface temperature during a sunny day down to about 45° F on a very cold (0° F) winter night, with an average wall temperature of about 73° F.

The second component of the solar heating system consists of two horizontal rock beds located under the living room and dining room. These beds are 2' deep and 10' wide, and one is 19' long while the other is 15' long. The rock beds contain 24 yards of 4" to 6" round, riverbed rock and are capable of storing enough heat to carry the house through a couple of sunless days.

Air is pulled out of the top of the greenhouse by two 1/3 hp. fans (one for each rock bed), blown through the rocks, and circulated back into the greenhouse. The controls are simple - a differential thermostat and two backdraft dampers. The heat trapped in the rock bed conducts up into the room through a 6" concrete slab cap and a quarry tile floor. The temperature of the floor along with that of the rock beds ranges between 85° F during the day to about 78° F after a cold night, or 70° after a sunless day.

Backup heating is provided by baseboard electric heaters with individual thermostats provided in each room. A two-panel, flat-plate collector array is located near the house for domestic hot-water heating. Summer cooling is adjusted by high and low vents in the greenhouse, which may be opened to exhaust heat and to draw cooling air through the house. In addition, the setback living spaces are shaded in the summer, thus avoiding direct heat gain. The principal contribution to summer comfort is the large mass of the building, especially the internal adobe mass wall.

The average summer temperature in Santa Fe is comfortable; about 70° F, but day/night fluctuation is large. The building mass levels out the fluctuation resulting in a comfortable environment. Although the greenhouse temperatures vary greatly (65° to 95° F), the mass wall protects the living spaces from these extremes.

Construction and Cost: Construction of the house began in January 1976 and was completed in August 1976 at a total cost of approximately $104,000. Part of the cost was offset by an $8,000 grant (representing about two-thirds of the cost of the solar portion of the house) awarded directly to the builders by HUD during the first cycle of the 1974 Solar Demonstration Act.

Performance: Test data obtined from 14 different points around the home on a Honeywell 16-point temperature recorded have shown that the house is apparently performing according to design requirements. Figure 7-36, which appears on the following page, shows a plot of data gathered during the period from January 3 to January 7, 1977. These data are generally representative of the lowest outside temperatures normally experienced in the Santa Fe area and illustrate the thermal stability of the house. During most of the winter, internal temperatures both upstairs and downstairs normally held in the upper 60's, the rock storage beds (which supply heat through the floors) normally maintained a temperature of 70° to 74° on sunny days.

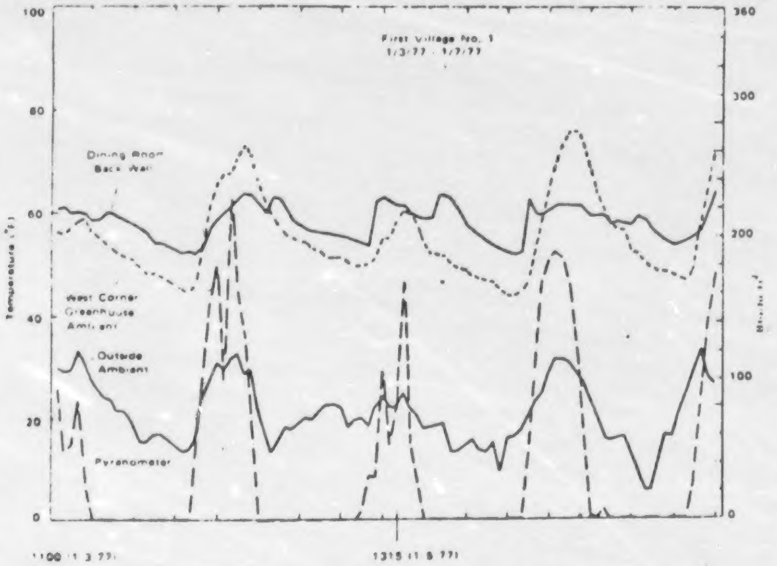


Figure 7-36: Representative Temperature Data

Apprehensions of summer overheating due to the sloping greenhouse have not been borne out. Greenhouse temperatures sometimes reach 90 to 95° near the top. However, this sets up a strong convection through the large window at the top of the stairway preventing any higher temperatures. The living spaces are effectively protected from the greenhouse by the adobe mass wall. The peak temperature observed in the lower level of the house during the 1977 summer was 75° despite peak outside temperatures of 95° F. Peak afternoon temperatures of 80° F have been recorded in the upstairs bedrooms, but they quickly drop after sunset to 70° or less.

Operational Cost: The house has been maintained at comfortable temperature levels for almost a year with minimal cost. Utility bills have consistently amounted to less than $10 per month even under the most adverse conditions, and usually the amounts were minimum service charges.

ISOLATED GAIN APPROACHES

In the isolated gain passive solar concept, solar collection and storage are thermally isolated from the living spaces of the building. The concept is contrasted with the direct gain passive solar concept where the collection and storage are integral with the living spaces, and with the indirect gain concept where collection and storage are separate from the living spaces but directly linked thermally. The isolated gain concept thus allows collector and storage to function somewhat independently of the building, while the building can draw from them as its thermal requirements dictate.

This concept utilizes a natural thermosiphon to move heat from collection to storage (Figure 7-37). It includes a collector space which intercedes between the direct sun and the living space, and is distinct from the building structure. A "thermosiphoning" heat flow occurs when a cool air or liquid naturally falls to the lowest point (in this case, below the collectors) and, once heated by the sun, rises up into an appropriately placed living space or storage mass, causing somewhat cooler air or liquid to fall again, so a continuous heat gathering circulation is begun.

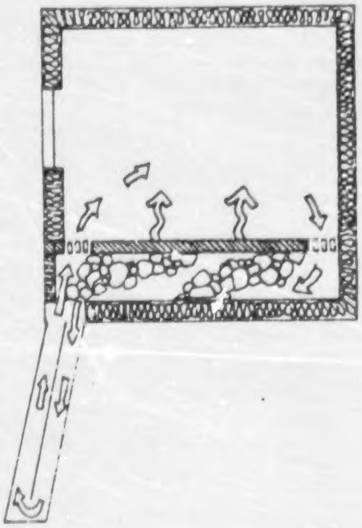


Fig. 7-37: Thermosiphon

Since the collector space is completely separated from the building space, the Thermosiphon system begins to resemble the active systems frequently seen on today's market. However, no external power from fans or blowers is needed to move the heat transfer medium. The Thermosiphon principle has been applied in numerous solar domestic hot water systems, and offers equally great potential for space heating application.

Requirements and Variations

The basic elements of the Thermosiphon system include a collector space, usually a storage mass, and a method of distribution. Solar heat is collected on a dark metal or wood absorber surface, heating up the adjacent fluid, which then rises naturally into a storage mass for convective or radiant distribution.

In the Thermosiphon solar building type, the collector location is not fixed by the building and thus can take maximum advantage of sun exposure. Since the collector area is separate from the building facade, the house is also flexible in its wall and opening design.

The solar storage mass can be located under the house floor, below windows, or in prefabricated wall elements. The storage location and material is the element of most variation and offers building and system design flexibility. Distribution is provided by radiation from the storage mass and by convection (naturally rising air movements) from storage or directly from the collector, a variation which must be considered in the design stages. The spatial arrangement of the building is critical in providing effective heat distribution.

Controls

In the Thermosiphon isolated gain building type, the link or contact area between the collector space and solar storage is not great, and can be easily blocked or disconnected to prevent air flow in adverse collector conditions (such as unwanted heat loss or overheating). However, controls must be carefully designed between the solar storage and the living space in order to meet the heating demands of the building and to prevent overheating.

The area of interface between the storage mass and the building will determine the speed with which the living space can be heated through radiation and convection. On the other hand, the greater the contact area between the storage and the living space, the more crucial is the control against untimely or overabundant space heating. For convective distrubution from the storage mass of a Thermosiphon passive solar building, controls similar to those used in the Trombe building types are required, including operable dampers and insulation panels.

ISOLATED GAIN APPLICATIONS

Davis House - Albuquerque, NM

Designer: P. Davis
Solar Engineer: S. Baer, Zomeworks
Completion Date: 1972

Climatic Data:
35° N
4,348 degree-days
0° F design winter temperature
100° F design summer temperature

Building Description: This one story wood frame house has 1,000 square feet of space arranged in an open interior plan with a loft. Insulation has been added through with a wall of books used to maximize the north wall section. Adobe end walls add to the thermal mass of the building.

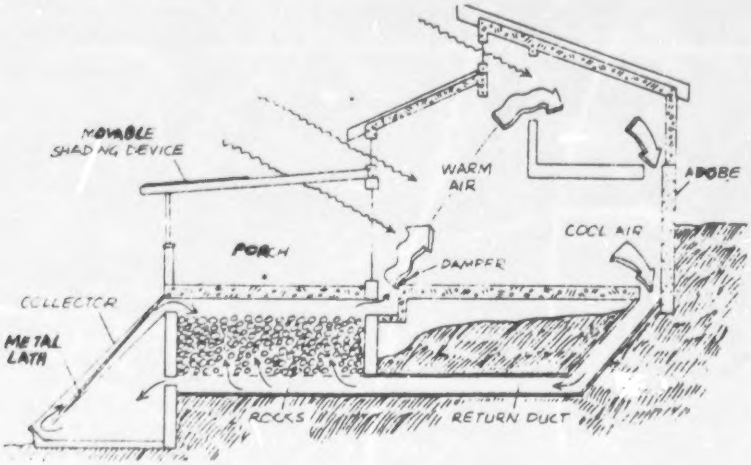


Figure 7-38: Davis House - Albuquerque, NM.

Solar System: 420 square feet of air collectors-single glazed with a block finished aluminum absorber panel - are located on the sloping ground in front of the house. Air is heated by direct gain and circulates through the collector by natural convection. The heated air rises to 45 tons of rock storage, which supports the floor of the south-facing porch. From here, heat is distributed through the house by radiation and natural convection. The heat supply is controlled by dampers which open and close the air ducts adjoining the living space. Domestic hot water preheat is provided by a thermosiphoning system with 80 square feet of collector.

Cooling Techniques: The south porch provides shading for the southern face, with overhangs to protect the clerestory windows. Cross ventilation is provided by the high clerestory windows.

Auxiliary: Electric heaters and a fireplace with heatilator recycle serve as auxiliary.

Performance Evaluation: 75% passive heating contribution.

HYBRID APPLICATIONS

Residential Application

A passive approach to solar heating, incorporating the Trombe (thermal storage) wall concept and direct solar gain, offers several advantages over active systems. Such a system is simple and has thermal and architectural advantages in that the Trombe wall not only forms all or part of the south wall of the house, but also serves as collector, storage, and build-in radiant heating panel. However, if not all rooms in the house communicate directly with the Trombe wall, control of heating is difficult. In this case, separated rooms tend to be cold and must be heated by different means. This suggests combining both passive and active features of solar heating in order to gain the advantages of each.

Such an approach was implemented by Dr. Bruce D. Hunn and his family in the construction of their three bedroom, 1,955 ft^2 house in Los Alamos, NM, which was completed in December, 1976. The house is located at an elevation of 6,600 ft, where the winters are cold (7,000 ^oF-days), but sunshine is plentiful.

The solar heating system is dominated by a two-story Trombe wall, about 300 ft^2 in effective area, covered with a double glazing. However, instead of a natural convection loop circulating air to the heated space, a blower circulates air through the Trombe wall air space and into a rock bed located beneath the house. A three zone, forced-air distribution system, with a natural gas auxiliary furnace, is connected to the rock bed. Additional solar collection is obtained by direct gain through 140 ft^2 of windows. A separage flat plate liquid collector array heats water going to a preheater tank for domestic hot water.

Design of House and Solar Heating System: One portion of the house is a two-story section whose south wall is framed by a 12' by 27' Trombe wall with large windows on each side for direct solar gain. The roof slopes from 27' at the south wall to 12' at the north wall of the garage. The first and second floors of this section were retained as large, continuous spaces in order to allow free circulation of air from the Trombe wall to the north side of the rooms.

Figure 7-38, on the following page, shows the floor plans for the entire house. A family/dining area, children's work area, and kitchen are on the first floor and are separated from the entryway and stairs by a 6' high wall that is open at the top. The east and west walls have minimum window area. All windows are wood frame and double glazed; all except three are casement type. The garage is attached to the north wall of the two-story section and acts as a buffer against heat loss. A 4" inside layer of slump block was placed in the entryway for additional thermal storage. These blocks with those of the Trombe wall were left unpainted inside the house, providing a pleasing interior decor.

The living room and study are upstairs on the south side, with the master bedroom and bath behind them. A storage area above the garage buffers this north wall, while a skylight provides light to the bedroom. The bedroom is separated from the living room by a 7.6' wall, which leaves a 3' space between its top and the sloping ceiling to allow for air circulation.

A single-story wing attached to the west wall of the two-story section contains a bathroom and two bedrooms. Its peaked roof has a 45°, south-facing slope on which are mounted the solar water-heating collectors. On each side of these collectors are 2' by 4' double glazed skylights that admit sunlight to the interior walls of the bedrooms in the winter. One bedroom has a rear wall constructed of 8" slump block that acts as thermal storage. Large windows on the south wall are the only windows in the wing, except for two small windows on the north wall of the hallway (Figure 7-39). With the exception of the Trombe wall, all walls and the roof are of 6" frame construction and filled with R-19 fiberglass batts. Beaded styrofoam, 2" thick, was placed on the foundation

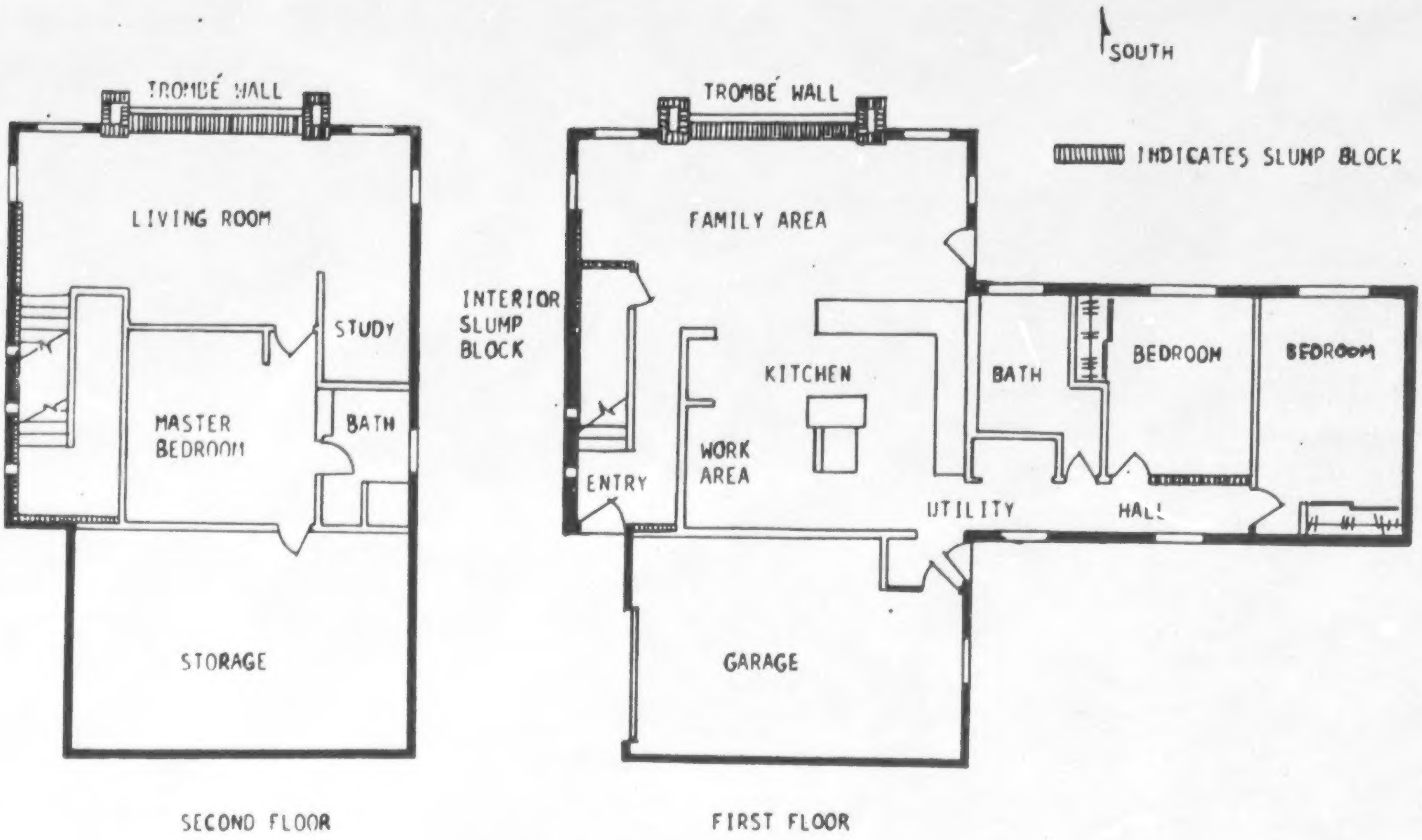

SOUTH
INDICATES SLUMP BLOCK
TROMBÉ WALL
LIVING ROOM
STUDY
MASTER BEDROOM
BATH
STORAGE
SECOND FLOOR
INTERIOR SLUMP BLOCK
TROMBÉ WALL
FAMILY AREA
KITCHEN
WORK AREA
ENTRY
BATH
BEDROOM
BEDROOM
UTILITY
HALL
GARAGE
FIRST FLOOR

Figure 7-39: Floor Plan

walls inside the crawl space. A conservative estimate of the heat loss for this design was calculated to be 8.5 Btu/^{o}F-day ft^{2}.

The basis for the solar heating system is a Trombe wall constructed of 1' open slump block that is completely filled with cement. This thickness has been shown to be optimal for concrete and the thermal condictivity is 1.) Btu/hr. ft.^{2} ^{o}F. The wall was heavily reinforced with No. 4 rebar and was structurally tied to the house by means of two 6" by 10" beams that support the second floor. The outside surface of the wall was covered with a dark brown stain that has a measured solar absorptivity of 0.91. A 2" air space separates the wall from the double glazing. The glazings are 0.25" standard plate glass spaced 2.5 cm (1") apart, and are mounted in sheets 46" by 90" in dimension on a wood frame bolted to the wall.

A 3' overhang shades the wall in the summer, and vents at floor level and at the top of the wall may be operated manually to purge the air space in order to prevent overheating. Because no air flows directly from this air space to the heated space in the passive mode, heating is strictly by radiation and convection from the inside surface of the wall. In the active mode, part of the heat received by the wall is removed at its outer surface and deposited in the rock bed via the blower circulation loop (Figure 7-40). In the charging mode,

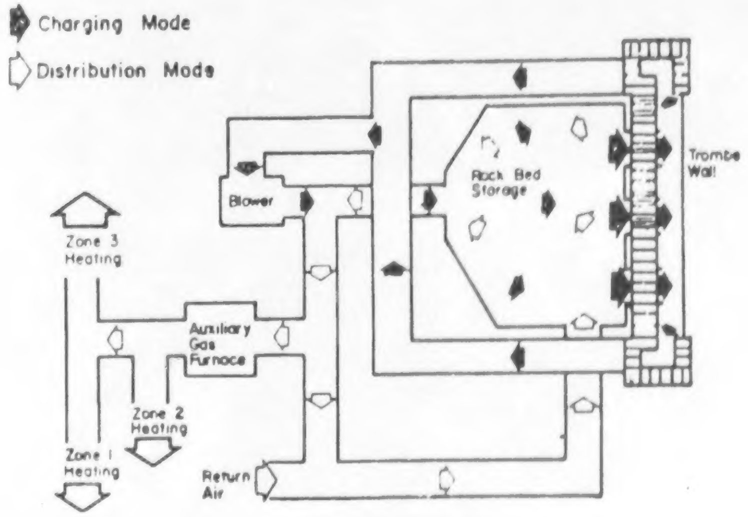


Figure 7-40: Heating System Flow Diagram.

a 500 ft^3/sec blower circulates air up through the Trombe wall air space, down through ducts mounted in columns on each side of the wall, and into a rock bed in the crawl space. A differential controller, which operates on the temperature difference between the top of the wall and the cold end of the rock bed, controls the charging process.

The rock bed is of the horizontal flow type, 6" in the flow direction with a 3' by 12' face, and is made of 12 tons of washed gravel that is 2" to 4" in diameter. The bed is insulated with extruded styrofoam, 2" on the sides and 3" on the top, and rests on a concrete footing. Plywood boards, 0.75" thick, are supported by 2" by 4" studs to form the frame.

A three zone, forced-air distribution system, with a natural gas auxiliary furnace, rated at 75,000 Btu/hr input, is connected to the rock bed (Figure 7-39). When any zone requires heat, returned air is ducted to the cold side of the rock bed, then out the warm end, and finally through the furnace. A thermostat located in the furnace inlet air stream turns on the furnace burner if the temperature of the inlet air is below a preset value of 80° to 85° F.

The system was completed with an active water-heating system that heats a 50-gallon tank used to preheat domestic hot water. The collectors are two 20 ft^2, Miromit modules mounted (at a 45° angle) on the roof of the single story wing. Air vents, controlled by a second differential controller that also operates the water circulating pump, allow the collector water to drain down to the preheater tank when the system is not charging.

Construction and Cost: The total (net) space-heating system cost (installed) was $5,436, including allowance for the exterior wall that was replaced by the Trombe wall. The domestic hot-water system cost (installed) was $1,260. This $6,700 incremental initial cost attributable to the solar heating system represents about 10% of the total construction cost of the house. This does not include the cost of the interior slump block in the entryway.

Performance: The house was first occupied in late December 1976, and three months of midwinter operating experience have been obtained. Because it was desired to test the space-heating system in a completely passive mode, the rock bed charging blower was shut off in early January, 1977. During construction, thermocouple rakes were installed at four levels in the Trombe wall to monitor the temperature gradient through the wall at its center. These temperatures, along with the ambient dry-bulb temperature, horizontal solar radiation, and wind speed and direction at the site were simultaneously recorded each hour.

Figure 7-41 depicts some temperature data taken during the period from January 24 to January 27, 1977. The wall temperatures were recorded at the 15' level.

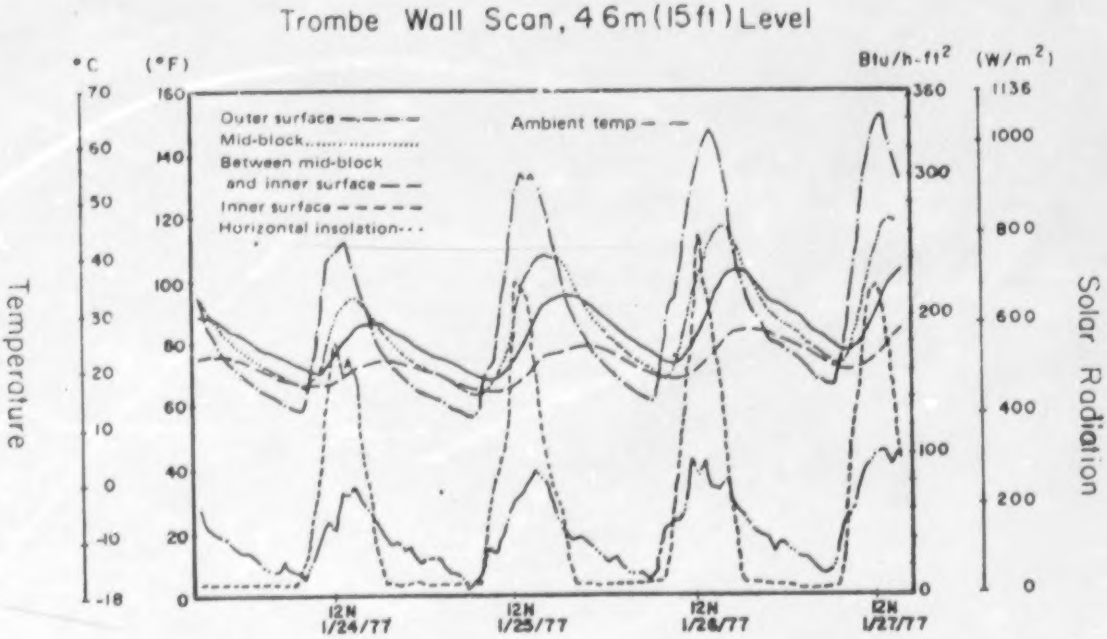


Figure 7-41: Representative Temperature Data

The well-behaved radiation readings indicate a typical clear and sunny, midwinter period where the average wall temperature steadily increased. Note that an outer surface temperature of 152° F was reached at midday. The peak temperature wave propagates through the wall in such a way that the peak at the inner surface approaches 90° F some 6 to 8 hours later.

Thus, the maximum T across the wall is about 75° F. While the outer wall temperature fluctuated from 56° to 152° F over the four-day period, the inner surface temperature ranged only between a high of 90° F and a low of 65° F, despite the fact that ambient temperatures reached 2° F in the early morning. Vertical temperature stratification in the wall is significant because of the stratification in the stagnant air layer between the wall and glazings. Measurements at the center of the wall in the early afternoon (peak temperatures) indicate a vertical temperature gradient of about 3°F/ft.

Operational Cost: Utility records for the first three months of 1977 are shown in Table 7-7 below. The gas usage included auxiliary space-and water-heating, a gas dryer (vented to the outside), and a gas stove. Besides the fact that January was significantly colder than Februray or March, the zone thermostat settings were also being adjusted during that month as operating procedures were being developed. Consequently, the house was kept slightly warmer during January than during February or March. After January, a thermostat setting of 60° F was maintained, except after two or more cloudy days, when the setting in one of the zones was raised to 65° F from about 8 a.m. to 10 p.m.

TABLE 7-7: UTILITY RECORDS (FIRST QUARTER 1977).

	Natural Gas Usage 10^3 liter (mcf)	Electricity Usage kWh	Degree Days °C-days (°F-days)
January	527 (18.6)	602	686 (1,235)
February	351 (12.4)	416	496 (892)
March	382 (13.5)	425	490 (882)

It is certain that the three month gas consumption of 44.5 mcf was considerably lower than that for comparably sized residences in Los Alamos, although no records were readily available for a comparable, non-solar-heated house. Nevertheless, it is estimated that this solar heating system was meeting approximately 60% of the winter load.

Commercial Application

Dove Publications, Inc., performs the editing and bulk distribution services for the Benedictine monastery located near Pecos, NM. In response to increased publishing activity, a decision was made to construct a relatively large warehouse in which printed material could be stored prior to its distribution and in which office space for the staff could also be provided. In view of the rising cost of heating fuels and other economic factors, a solar type construction was selected for the design of this building.

The design was adapted to the specific function which the building was intended to serve. In particular, the warehouse may be maintained at a generally lower temperature than the office space, and temperature control in the offices is not critical during nonworking hours. Consequently, the design provides for the warehouse to be heated predominantly by direct solar gain, whereas the offices are heated by a combination of direct solar gain and thermal storage techniques, utilizing a water-filled drumwall as the thermal mass for collector and storage. The system is totally passive, requiring no fans or other mechanical equipment for its operation.

Backup heating for the 10,000 ft^2 structure is supplied by radiant electric heating panels, and a separate flat plate collector array is provided for domestic hot-water heating. Located at an elevation of nearly 8,000 feet, the building was completed for operation in August. 1976.

Design of Building and Solar Heating System: The total floor space in the building is about 10,000 ft^2, which includes an unheated basement. The south portion of the building (approximately 2,800 ft^2) contains the mailroom, offices, and living quarters for the one full-time occupant. The drums from the drumwall protrude up into the office areas, but are enclosed in insulated cabinets that conveniently double as counter-height working areas. The north portion of the building contains approximately 5,500 ft^2 of warehouse space.

The south side is dominated by three 140' long rows of insulated glass windows encompassing a total of 1,550 ft^2 of glazing. The large, upper (clerestory) windows admit sunlight to the warehouse (see Figure 7-42 on the following page), and provide the direct solar gain on which the heating of the warehouse is primarily dependent. The middle row of windows admits sunlight to the offices, providing direct gain during working hours and significantly supplementing the heating available from the drumwall.

The lower row of windows (440 ft^2) provides the glazing in front of the water-filled drumwall. All windows are thermopane. There are no openings on the north side, with the exception of a large garage door, and vents are available in the east and west walls to drain off excess heat, should overheating occur.

The outer walls are of concrete block masonry construction, with an additional 2" of styrofoam insulation added on the inner surface (for ease of installation). Styrofoam insulation 1" thick was placed around the perimeter of the foundation below ground level, and the roof is insulated with 6" of

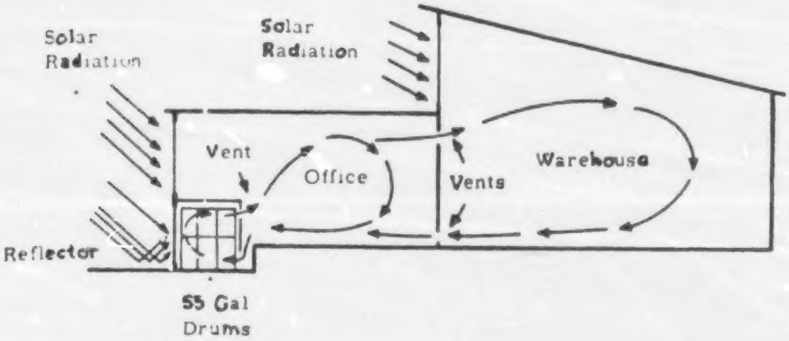


Figure 7-42: Solar Heating System

fiberglass. A center bearing wall constructed of concrete blocks filled with sand separates the warehouse from the office space and also provides thermal mass in addition to that provided by the drumwall. The interior office walls are of a simple frame construction with 2" by 4" studs.

Figure 7-42 also illustrates a simplified diagram of the solar heating system for this building. The most prominent feature of the solar heating system is a water-filled drumwall designed for thermal collection and storage. This drumwall consists of 138 standard 55-gallon barrels painted black and filled with a water/propylene glycol mixture to which 8 ounces of 10 wt. oil has been added. The drums are about 90% full (approximately 50 gallons per drum) to allow for thermal expansion.

The drumwall extends the full length of the building on the south side and is accompanied by aluminum reflecting doors outside of the south wall, which are hinged and closed at night to aid in heat retention. These reflecting doors were left uninsulated because the design worked so well even without insulation. The warehouse section is heated by direct gain through the glazing in the clestory of the building. In addition, vents between the office area and the warehouse may be opened to allow excess heat from the offices to be pulled off into the warehouse. Air circulation is achieved by natural convection, with no fans being used. The offices are heated by a combination of direct solar gain through the windows and heat released from the drumwall. Each office has a bank of registers on the side of the counter which covers the drumwall, and cold air returns are situated on the floor at the base of the counters approximately 3' to 4' from the heat registers. These registers are manually operated and are normally opened only at night to admit heat released by the drumwall. During the day, direct gain through the windows is usually adequate to satisfy the heating requirements of the offices.

The backup heating system in the offices consists of nine 1,440 watt radiant electric heating panels which are manually controlled. Normal operating procedure has been to utilize the backup heating system only when the office temperature falls below 68° F. A two-panel, flat-plate collector is located at the southwest corner of the building for domestic hot-water heating. Air-conditioning has not been provided nor has it appeared to be necessary.

Construction and Cost: The total construction cost of approximately \$130,000 corresponds to a unitary cost of only \$13/ft^2. Of that total, approximately \$8,500 is attributable to the solar portion of the building.

Performance: Although the warehouse was designed to maintain a minimum temperature of 45° F, the average minimum temperature maintained thus far has been 50° F, and the lowest temperature seen in the warehouse has been 48° F, which was seen on only two or three occasions during the winter. The solar heating system has usually maintained a temperature of 62° to 65° F in the offices when the doors are closed, and the lowest temperature seen in the offices (55° F) occurred only during nonworking hours.

Instrumentation provided by Los Alamos Scientific Laboratory has been used to monitor the temperature performance of the drumwall. Figure 7-43 illustrates

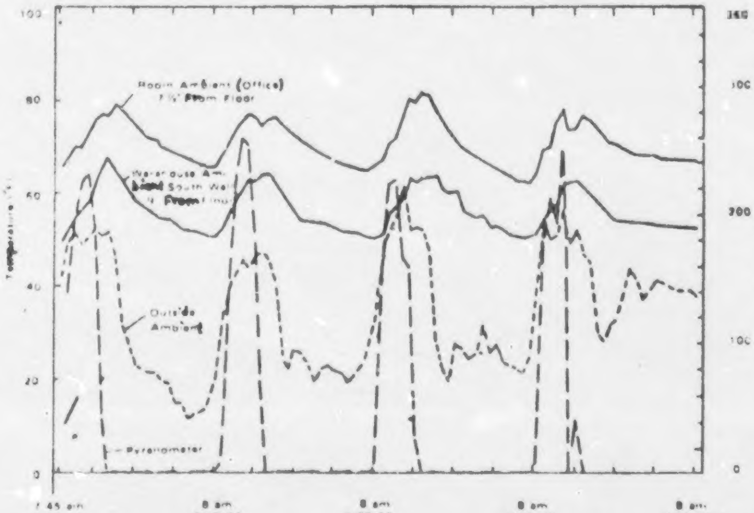


Figure 7-43: Representative Temperature Data.

representative data collected during the period from February 18 to February 22, 1977. Notice that the office temperatures ranged from 62° to 78° F and the warehouse temperatures averaged above 50° F during this period, even though the outside temperature often dropped below 20° F. The owners have observed a predictable 12° F temperature variation in the warehouse from the winter to the summer.

Operational Cost: Fuel costs for this building have been minimal since the backup heating system has rarely been needed. In fact, the one full-time occupant who resided in the building during the entire winter did not find it necessary to use the electric backup heating at all. Only during March and April, when several sunless days occurred, was it necessary to employ the backup heating system during working hours. Nevertheless, the total cost of heating electricity for this building from the time it began operation in August, through June, 1977 (nearly 11 months), amounted to only $80.63.

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